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MATERIALS AND THEIR PROPERTIES

by

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With Diagrams
and Photographs

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think you have
the scientist calls Sucrose.

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white in colour. It has no smell but if you

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CHAPTER I

TO INTRODUCE YOU TO OUR SUBJECT

A FEW weeks ago I was talking with a friend about another man whom I thought he knew.

" Surely," I said, " you know Smith."

" What's he like ? " asked my friend.

" Well," I replied, " he's a fairly young man, aged about 25, tall, but rather thin. His face is long and pointed. He bends forwards when he walks—I think he hurt his back in an accident a few years ago ; you often see him passing this way in the mornings."

" Yes," said my friend, " I think I know him. Doesn't he work in a shop somewhere in the town ? "

" That's right," I said, " he serves in a book-shop."

And so my friend was able to recognise the man I was talking about. I had described Smith in such a way that it was quite clear whom I meant.

In science we sometimes need to describe various kinds of materials. Let us take Glass as an example. Of course you know what Glass is, but imagine you are describing it to someone who is not sure what material is given this name. " Glass," you say, " is a fairly hard material, usually colourless, and so clear that you can see through it. It breaks easily if you drop it or try to bend it." And if your friend still does not recognise it, you might also say that it is the material commonly used for windows. You *describe* the material and say *what it can do* (or what it is used for). Perhaps you think you have never seen the material which the scientist calls Sucrose. Let me describe it to you. It consists of many little grains, usually white in colour. It has no smell but if you put some in your mouth it tastes sweet. It dissolves (melts) easily in water, or in tea, and gives it a sweet taste . . . But need I say more? You have already recognised the material; we commonly call it sugar.

We can describe a material by stating its colour, smell, taste, strength, hardness, and so on. We call these qualities of the material its "properties." Some materials have similar properties but no two materials have *all* their properties alike. Thus salt and sugar are both white and consist of grains, but they have different tastes. Besides describing the nature of a material we can also say the kinds of things it can do. One of the most important properties of coal, for example, is that it can burn and so make heat. This is far more important than the fact that it is black! An important property of copper is that it can carry an electric current easily; the chief property of a certain medicine is that it can cure a fever.

What, do you say, are the obvious properties of water? It is a colourless liquid, without taste or smell. It runs easily (unlike thick oil). If you make it cold enough it freezes into a white solid (ice) and, if you boil it, it changes into a colourless gas (steam). We could, if we like, say exactly at what temperature it freezes and at what temperature it boils; we could state its weight (a gallon of water weighs 10 lb), and so on. You can amuse yourself by describing a material to a friend and seeing if he can recognise it. Here are some materials you can try: sand, diamond, petrol, air, wood, clay.

We may not need to describe a material very often in everyday life, but, in many cases, we use a material because we know it has the properties we need. If you spill some ink on the table you need a material which can quickly soak it up. You use a piece of blotting-paper (or perhaps a piece of rag) because you know that it has this property.

You use string for tying up a parcel because you know that it is strong and can bend easily; you put wood on a fire because you know that it burns well. A potter makes his cups from clay. He knows that he can shape the clay when it is soft and damp and that the clay will become hard when he bakes it. Similarly, a shoe-maker chooses leather with which to make his shoes, a builder makes his walls of brick or stone, an engineer makes his machines of steel, and so on.

Sometimes we know the properties which we want but must stop to think which material has all, or most, of these properties. A man, perhaps, is building a hut in a field. The roof, he says, must keep out the rain, must not be too heavy, and must be able to last a long time. (And, he might add, the material must be cheap.) He probably decides to make the roof of metal sheets. The metal may be rather heavier than he wants but, in other ways, it is the most suitable material for his purpose. About 60 years ago, when the idea of the electric lamp had been thought out, men were wondering what material could be used for the filament (thin wire inside). The material must be able to carry an electric current and also be able to withstand being made very hot. At that time only one material was known which had these two properties. The material was carbon—the black stuff which is made when wood half-burns away. So the filaments in early electric lamps were made of carbon. Some years later, a new, rather uncommon metal was discovered. It is called tungsten. It can carry an electric current and can be made very hot without melting. A tungsten filament gives a brighter light than a carbon filament and all lamp filaments are now made of this metal.

Sometimes we know the properties which we want but no material is known which has these properties. Scientists try to find ways of making new kinds of materials. For hundreds of years the silk threads made by silkworms (p. 69) have been woven into cloth for dresses. But silk is not a cheap material ; at one time it was used only for dresses of kings and other important people. But scientists have found ways of making similar threads cheaply from wood and all of us can have " artificial silk " clothes. Many different kinds of steel have been invented. Some are very hard, some are springy, some are very strong, and so on. Each kind has its special uses.

We must not think that scientists are interested only in the uses of different kinds of materials. They are also interested to know *why* each material has its particular properties. Why are diamonds hard ? Why does blotting-paper soak up ink ? Why is gum sticky ? Why does oil help a wheel to turn smoothly on its axle ? These are the kinds of questions which a scientist asks. In trying to find the answers to questions like these he adds to the knowledge which men have about the world around them. That knowledge may enable them to make their lives more useful, more comfortable, more pleasant. And, of course, the scientist tries to find the answers to his questions because he likes to do so. He likes to find out all he can about the world in which he lives. Perhaps you are reading this book for a similar reason.

What, then, is this book about ? We shall read about the properties of various materials. We shall read, for example, about the strength of metals, the hardness of diamonds, the stretching of a piece of rubber. We shall be specially interested to see what uses can be made of various materials because of their special properties. And, like the scientist, we shall also try to find out why the materials have these properties and so learn a little more of the wonders of Nature.

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CHAPTER II

SOLIDS, LIQUIDS, AND GASES

WE all know that iron is a solid, water is a liquid, and air is a gas. There are three kinds of materials: solids, liquids, and gases. We can usually tell fairly easily whether a material is a solid, a liquid, or a gas. Thus we know immediately that stone, wood, glass, and metals are solids, that petrol and lamp-oil are liquids, that air and steam are gases. So we already know, roughly, the differences between these three kinds of materials, but what, exactly, are the differences?

If you put a piece of iron on your table and come back to look at it after an hour, you would be very surprised to find that it had changed its shape or had become bigger or smaller. Iron is a firm material; a piece of iron keeps its shape and keeps its volume (size). This is true of all solids. A solid keeps its shape and has a fixed volume. This does not mean, of course, that we *cannot* change the shape or volume of a solid. We can change the shape of a piece of soft clay, we can stretch an iron bar if we use very strong forces, and all solids expand (grow in size) very slightly if we heat them. But a solid keeps its shape and volume if we do not use such outside forces.

What happens when you spill some water on the table? It quickly flows and spreads over the table. You cannot make a heap of water. A liquid is not firm; it cannot keep its shape. To stop a liquid from spreading we must put it in a container. Then it takes the shape of the container. We can pour a liquid from one container to another. Although the shape of a liquid is not fixed, its volume is fixed. Even very strong forces can scarcely change the volume of a liquid. You cannot push two pints of water into a jar which can only hold one pint. One pint of water can never fill a jar which can hold two pints. The water goes to the lower part of the jar and leaves the upper part empty. A liquid, then, has a fixed volume but not a fixed shape.

A gas cannot keep its shape. The air in a bicycle tyre has the shape of a ring but if you make a hole in the tyre the air flows out and so changes its shape. The shape of the air in a room is the same as the shape of the room, but the same air would have a different shape if it were in a different room. A gas, like a liquid, has no fixed shape, but it is different from a liquid in another way. Suppose you put a few drops of petrol on the table. Very soon you can smell it all over the room. Some of the petrol changes into a vapour[1] (gas) and the vapour spreads. If we take a container from which all the air has been pumped out and then let in again the smallest amount of air, this air spreads to fill all the container. A gas is not fixed in volume; it always spreads and fills its container. In a similar way, we can compress a gas, that is, press it into a smaller space. We can press more gas into a container which is already "full." You do this, for example, when you pump up a bicycle tyre. A gas, then, cannot keep its shape and its volume is not fixed.

Let us just go over these differences between the three kinds of materials again. A solid has a fixed volume and keeps its shape, liquids and gases do not have fixed shapes but whereas a liquid has a fixed volume a gas has not.

Although we can put most common materials into one of the three classes fairly easily, there are some materials about which we must stop to think. We can pour a liquid from one container into another. Is treacle a liquid? Yes, we can pour it, although it flows slowly. It is a thick, sticky liquid. So, also, is tar a thick, sticky liquid. Do you know the black material called "pitch"? It is a kind of hard tar. A piece of pitch feels quite firm; we might think it is a solid. But if you leave it in a box for a long time (e.g. a year) it gradually takes the shape of the box. Fig. 1 shows what happens if you put a piece of pitch in a glass "funnel." In the course of years it flows through the funnel. Pitch is therefore really a liquid but it is a *very* thick one.

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[1] A vapour is merely a gas which can easily be changed back into a liquid.

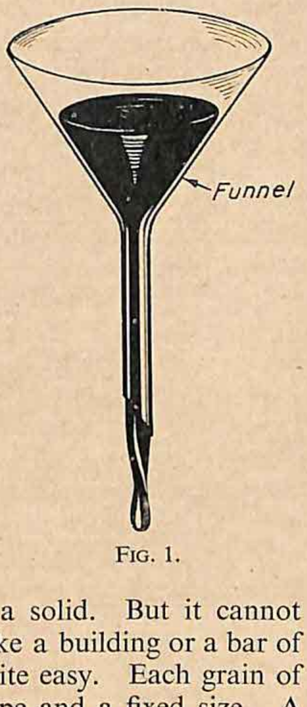

FIG. 1.

What kind of material is dry sand? Of course you say it is a solid. But it cannot keep its shape. You cannot make a building or a bar of dry sand. The explanation is quite easy. Each grain of sand is a solid with a fixed shape and a fixed size. A heap of sand consists of thousands of grains. These little grains slide and roll on each other so that a heap cannot keep its shape.

Thick, slippery mud is a curious material. Is it a solid or a liquid? The answer is that it is a mixture of both. Mud consists of thousands of small particles of clay (solid) each surrounded by water (liquid). Smoke is another curious material. It too is a mixture. It consists of thousands of particles of solid floating in a gas (air). And what kind of material would you call a jelly? That is rather a problem. We shall try to answer this question in a later chapter.

Some materials can exist as solid, liquid, or gas. Think of the wax in a candle. It is a solid. When you light the candle, some of the wax melts and so becomes a liquid. The liquid then turns into a vapour and burns in the flame. These changes from one kind of material into another are caused by heat. When you boil some water in a pot on the fire, the heat changes the liquid (water) into a vapour (steam). If the steam is cooled it turns back into water. A pool of water " dries up " in the sunshine. The water slowly and gently turns into vapour, or, as we say, it " evaporates." If water is made cold enough it turns into a solid—ice. If ice is heated it melts and turns back into water.

In our daily lives we usually see a material in only one of the three forms. Thus we usually see iron as a solid, air as a gas, and so on. This is because we do not often use very high or very low temperatures. But, if iron is made hot enough, it melts to form a liquid; if air is made cold enough it changes to a liquid. Many materials, of course, cannot exist in the three forms. Heating or cooling destroys them. You cannot, for example, melt wood; it burns when you heat it.

Gases mix very easily with each other. We know that petrol vapour mixes with air; a little petrol soon

(By courtesy of Imperial Chemical Industries Ltd.)

A block of solid carbon dioxide. (Carbon dioxide is a gas at ordinary temperatures.)

mixes with the air in a room so that we can smell it everywhere. Even air itself is a mixture of gases. The chief gases in the air are oxygen (about 1/5) and nitrogen (about 4/5). These gases are so well mixed that any part of the air is exactly like any other part of the air. Suppose we take two tall jars, A and B, fill each with a different gas, and then stand them one on the other with their open ends together (Fig. 2). Suppose we arrange them so that the *heavier* gas is in the lower jar B. We might think that the heavier gas will stay at the bottom. After a short time, however, *both* jars contain a mixture of the gases.[1] The gases mix of their own accord, that is, without outside help.

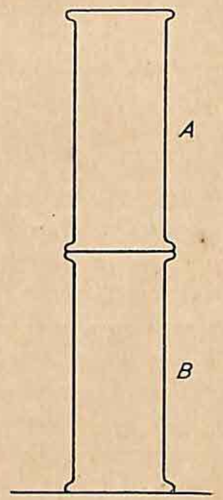

FIG. 2.

Solids do not mix of their own accord. If you leave a coin on the table, the metal does not mix with the wood! We can *make* a mixture of two solids, especially if we first grind the solids into powders. We can mix some salt with some sand. But if we look closely we can see the separate particles (grains) of salt and sand. We can make a mixture of two metals by melting them, pouring the liquids together, and letting the mixture cool to form a solid again. In such a mixture we cannot see the separate particles of each metal. Brass is such a mixture; it is made of copper and zinc.

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[1] This can easily be shown in a school science room by using bromine and air. Put a few drops of bromine (a red-brown liquid) in the lower jar. It produces a red-brown vapour which mixes with the air in the upper jar.

Gases, then, mix easily of their own accord, solids do not mix of their own accord and, even when mixed by man, do not always make good mixtures. Can we mix liquids? If you pour some milk into some water, and stir them together, you find that they mix perfectly. Every drop of the mixture contains both milk and water. In a similar way we can make perfect mixtures of water and alcohol, and of petrol and motor-oil. But there are some pairs of liquids which do not mix with each other. Pour some oil into some water and shake them together. You can see drops of oil floating in the water. But the oil drops gradually come to the top and after a time the oil forms a separate layer on the top of the water. The liquids do not mix.

Suppose we choose two liquids which, we know, can mix. If we put them together, taking care that there is no shaking or stirring, will they mix of their own accord? You may like to try this experiment. You need a large jam-jar and a small jar which you can stand inside it. You also need the substance called copper sulphate (blue vitriol). You can probably get some at a chemist's shop. Put some of the copper sulphate into some water and stir well so that you make a blue solution. In the experiment you are going to test the mixing of copper sulphate solution and water. First test that the ilquids can mix. Put a little of the solution in a dish and pour in some water. They mix immediately. Now nearly fill the small jar with the solution and stand it in the jam-jar. (You may find it easier to put the small jar in the jam-jar first and then fill it.) Then, very gently and carefully, fill the jam-jar with water. Take care not to let the stream of water disturb the solution in the jar. You find that you have a small jar of blue liquid standing inside a bigger jar of clear water (Fig. 3). It may surprise

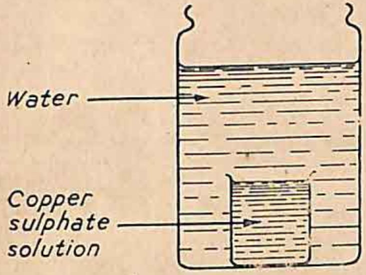
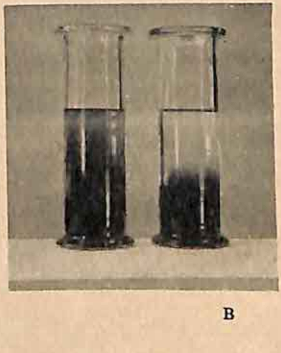


FIG. 3.

you to see that the liquids do not mix. They certainly do not mix as readily as gases. But leave the jars in a place where they will not be disturbed. Very gradually the copper sulphate solution mixes with the water; it may be several weeks before they are fully mixed. Copper sulphate solution is heavier than water. But it slowly spreads, of its own accord, through the water.

Now let us examine the mixing of a solid and a liquid. Put a spoonful of powdered chalk into a jar of water and stir them together. The chalk mixes with the water so that the liquid looks something like milk. But if you look carefully you can see the particles of chalk floating about in the water, and, after a time, the particles settle at the bottom. The mixture is not a good one. We can easily separate the chalk from the water. Cut a circle about 6 inches across from a piece of blotting-paper (Fig. 4 *a*). Fold it in halves and then in quarters (see *b*). Open out the paper as shown in (*c*) so that there is one thickness of



(*W. E. F.*)

The mixing of liquids. Some coloured solution was put in a jar and pure water carefully added on the top. The liquids did not mix (as shown in the right-hand jar). After a week the liquids had mixed of their own accord (as shown in the left-hand jar), although the heavier liquid was at the bottom.

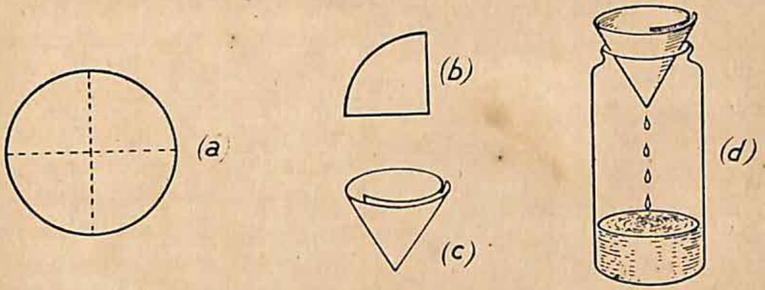


FIG. 4.

paper on one side and three thicknesses on the other, i.e. make the paper into the shape of a cone. Stand the paper cone in the top of a jam-jar and pour some water into it.[1] The water slowly drips through. It passes through the very small holes in the blotting-paper (p. 37). Now pour a mixture of chalk and water into the cone. Clear water drips through. The particles of chalk stay behind on the paper ; they are too big to pass through the holes. In this way we separate the solid from the liquid.

Put a little sugar in a jar of water and stir it. The sugar disappears. We cannot see particles of sugar floating about in the water. We know that the sugar is there because the water tastes sweet and because the sugar is left behind if the water dries up. It seems that the sugar breaks up into such small particles that we cannot see them and they spread evenly through the water. We say that the sugar dissolves in the water. The liquid which is made is called a solution. Salt, copper sulphate, Epsom salts, and soda are other examples of solids which can dissolve in water. Chalk, sand, iron, glass, and wax are examples of solids which do not dissolve in water.

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[1] A scientist uses a thinner piece of paper and supports it in a funnel.

Can we separate a dissolved substance from the water by pouring the liquid through a blotting-paper cone? Try it with solutions of salt, sugar, and copper sulphate in turn. With the first two solutions a clear liquid runs through. Taste this liquid. The taste (salt, sweet) shows you that the *solution* runs through. With the third solution (of copper sulphate) there is no doubt that the solution runs through; it is coloured blue. We cannot, therefore, separate a dissolved solid from water in this way. It seems that the particles of solid are so small that they pass through the holes in the paper.

In this chapter we have learned the chief differences between solids, liquids, and gases. We have learned that gases mix easily, some (but not all) liquids can mix, but solids do not mix of their own accord. We have seen that when a solid dissolves in water the mixture is so good that we cannot separate the solid by using a blotting-paper cone. These are *facts* about solids, liquids, and gases; we know that they are true because we can test them. Now we must try to find the reasons for these facts.

CHAPTER III

ATOMS AND MOLECULES

THE men of ancient Greece thought it strange that wine and water could be mixed together. We can mix a pint of wine with a pint of water, and every drop of the mixture contains both wine and water. We can mix a pint of peas with a pint of beans because the separate peas and beans can get between each other. In a similar way we can mix red marbles with blue marbles, we can mix the nails from one bag with those from another bag. Obviously we can mix things if they consist of many small bits (like the peas, beans, marbles, nails). But do water and wine consist of small bits? Further, the mixing is so good that the bits must be very small. The men of long ago could not believe that water and wine consist of very small bits.

But scientists now believe that all materials (solids, liquids, and gases) are made up of very small particles (bits). A pint of water, for example, consists of millions of very small water-particles. There are many good reasons for believing this but we cannot state them shortly here. We shall see, as we read this book, that the idea of particles explains the natures and qualities of various materials very well and this is why we believe that the idea is true. We have already seen that the idea of particles enables us to explain mixing.

The simplest kind of material is called an " element." Iron is an element. We cannot, by heat, electricity, or any other means, get different materials out of it. It consists of just one kind of material, iron. Other well-known elements are gold, tin, copper, carbon, sulphur, oxygen, nitrogen, hydrogen. There are rather more than 90 different elements but only about 20 of them are common.

Suppose we take a small piece of iron and cut it into two. Let us cut the bits into two, cut the new bits into two, and so on. When the bits are about 1/1000 inch across they are too small for us to see. Let us suppose that, in some magic way, we can go on cutting and cutting. (Actually we could not make a knife small enough and we could not see the bits !) At last we should get little bits of iron about one hundred-millionth of an inch across. These are the particles of which the iron is made. We cannot, by the use of any reasonable force, cut up or split these particles. We call them ATOMS. (The word comes from two Greek words which mean "cannot be cut.") The piece of iron with which we started consists of millions of iron atoms.

You may wonder why we cannot cut up atoms. You may also have heard of "splitting the atom." It is true that scientists have now found ways of breaking atoms but the bits which they get are quite different from the material with which they started. Think of a crowd of people. We can divide the crowd into smaller and smaller groups and at last we shall have groups each containing only one person. We cannot make smaller groups. We can, by more violent means, cut up the people. We shall get arms, legs, ears, and so on ! But you would not say we are making smaller groups of *people*. A crowd consists of people and the smallest group we can have consists of one person. In a similar way, a piece of iron (or other element) consists of atoms ; we cannot have a smaller piece of iron than one atom.

The atoms of each particular element are exactly alike. All iron atoms, for example, are alike. But atoms of different elements are different. There are about 90 different kinds of elements and so there are about 90 different kinds of atoms. As atoms are very small things it is surprising that scientists have been able to measure their sizes. The different kinds of atoms are slightly different in size but all are about one hundred-millionth of an inch across. This means that 100,000,000 atoms would have to be laid end to end to make an inch. Similarly, different kinds of atoms have different weights. The lightest atom is the hydrogen atom. An iron atom is 56 times as heavy and the heaviest atom (uranium [1]) is 238 times as heavy as the hydrogen atom. How many iron atoms, do you think, would make an ounce ? Well, write down the number 3 and then add 23 noughts ! We cannot possibly understand this very great number. If these atoms were shared among all the people of the world, and each person began to count them at the speed of 4 a second, no one would live long enough to count his share !

Although there are only about 90 different elements, there are thousands of different kinds of materials. Wood, sand, water, petrol, glass, air are examples of common materials which are not elements. A few materials are mixtures of elements (air consists chiefly of the two elements oxygen and nitrogen). Most materials are either compounds or mixtures of compounds. A compound consists of several atoms *joined* together. Water, for example, is a compound of hydrogen and oxygen, sand is a compound of oxygen and a seldom-seen element called silicon. Wet sand is obviously a mixture of two compounds. Wood, petrol, and glass are further examples of mixtures of compounds.

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[1] This is the heaviest element which is found naturally in the earth. In the last few years scientists have been able to make certain heavier elements.

We know that water is a compound because we can "decompose" it; we can break it up into its elements. (This can be done by passing an electric current through it.) We can always get simpler substances (elements) out of a compound, though it is not always easy to do so. We must be careful to learn that in a compound the elements are *joined* together. Water is not a *mixture* of hydrogen and oxygen. Such a mixture would be a gas, because each of the elements is a gas, and we could mix the gases in any amounts we choose. But the compound water is quite different from the two gases from which it is made. It is a liquid. Further, water always consists of 8 parts (e.g. 8 lb) of oxygen joined with 1 part (e.g. 1 lb) of hydrogen. In a similar way the compound made from iron (a grey solid) and oxygen (a colourless gas) is a brown solid something like rust.

Now suppose we can cut up a drop of water into smaller drops. Each small drop is just the same as any other, so each drop, however small, must contain hydrogen and oxygen. If we imagine we cut up the drop as we cut up the iron, we should at last get little particles one hundred-millionth of an inch across. Each particle is the smallest amount of water we can have. It consists of two hydrogen atoms joined to one oxygen atom (Fig. 5). If we break up this particle we get the separate atoms.

So the smallest particle of a compound consists of several atoms joined together. We call such a particle a MOLECULE. (The word molecule means "a little mass.") A molecule of silica (sand) consists of two oxygen atoms and one silicon atom. An alcohol molecule consists of two carbon atoms, six hydrogen atoms, and one oxygen atom joined together in a particular way. The molecules of some compounds, such as starch, consist of many

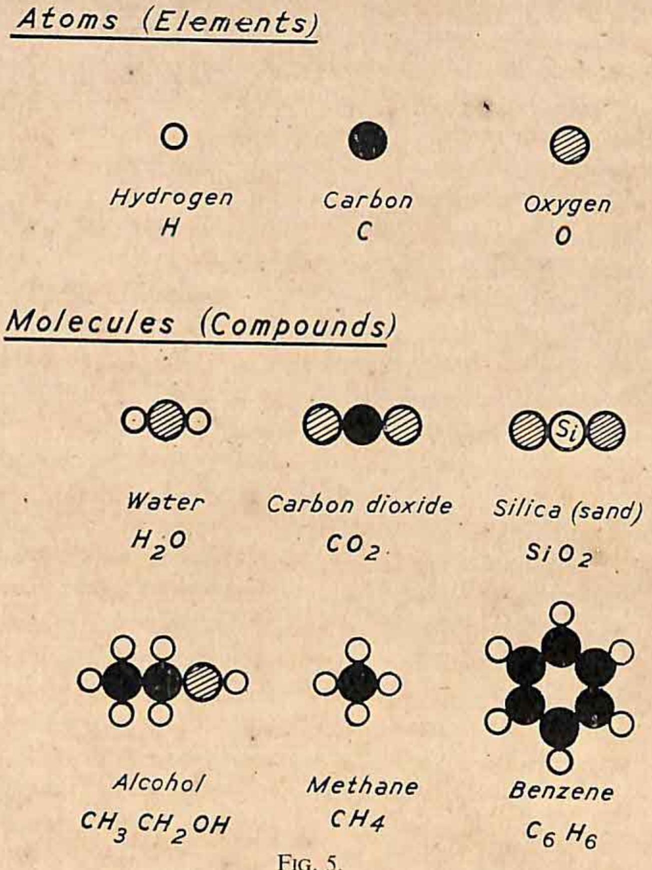

Fig. 5.

atoms. We shall read about some of these very big molecules in Chapter XIII.

The drawings of Fig. 5 may help you to understand the ideas which we have been describing. In these drawings the atoms are shown as little balls. Do not think that atoms are actually shaped like balls, but it is convenient to draw them so. Notice that the molecules of compounds consist of several atoms joined together. Notice the molecule of alcohol. It consists of nine atoms. (There is another compound (a kind of ether) which consists of the same nine atoms but the atoms are joined together in a different pattern.) Methane is a gas which burns; benzene is a well-known, runny oil.

The scientist uses letters instead of balls to represent atoms. He uses H for a hydrogen atom, O for an oxygen atom, and C for a carbon atom. Then a water molecule, which consists of two hydrogen atoms and one oxygen atom, can be written H_2O. Similarly, a molecule of carbon dioxide,[1] which consists of one carbon atom and two oxygen atoms, is written CO_2. A molecule of alcohol is written CH_3CH_2OH (or C_2H_5OH), thus showing how the atoms are arranged.

All materials, then, are made of particles. Usually the particles are molecules but in an element (such as iron) the particles are atoms. But we know that there are three quite different kinds of materials: solids, liquids, and gases. How can we explain the differences between these kinds?

We can easily walk through a gas; we move through the air every day. We can easily push the particles aside and make a way between them. It is not so easy to move through a liquid. We cannot swim as fast as we can walk; a ship cannot travel as fast as a train. We must *push* a way between the particles of a liquid. A force holds the particles together. We must overcome this force when we wish to push them aside and make a way between them. We cannot walk at all through a solid thing like a wall or a tree. The particles are firmly held together. We cannot, without great force, separate them and make a way between them.

[1] This gas forms the impure part of the air which we breathe out.

The force which holds the particles of a material together is called the force of "cohesion." This force is very strong in a solid, less strong in a liquid, and very small indeed in a gas.

In a solid the particles are closely packed and firmly held together. Very often they are arranged in regular rows in a pattern (see Chapter IV). They cannot move about and change their positions but they can vibrate (shake) slightly backwards and forwards. We can understand that a material made of such strongly-held particles is firm and has a fixed shape. Now suppose we heat the solid. The particles vibrate more strongly; they swing further from their proper positions. At last they break away from each other; the force of cohesion can no longer hold them in their places. Instead, there is a heap of particles, all moving about as they wish. The solid has melted!

In a liquid the particles are free to move about but they are still fairly close to each other. The force of cohesion is strong enough to keep the particles together, so that the liquid has a fixed volume, but not strong enough to stop them from moving about. We can understand why we can pour a liquid from one container to another. The particles can "roll" over each other. It is less easy to realise that the particles are moving about. If the particles were big enough for us to see, we should find that they move in zigzag paths as they hit into each other. An interesting experiment was made by a scientist named Brown. He obtained some pollen grains from flowers, put them in water, and examined them with a powerful microscope. Pollen grains are *very* small. Brown saw that the grains in the water were shaking about and moving in an irregular way. They were being hit, over and over again, by the moving water molecules.

We can understand why many pairs of liquids mix with each other, and, if left long enough, mix of their own accord. The particles of each liquid are free and are moving about. The particles of one liquid can move between the particles of the other liquid. Some liquids, like water and oil, will not mix. The force between two water molecules is stronger than the force between a water molecule and an oil molecule. If a water molecule begins to move into the oil, the other water molecules pull it back. The water molecules thus stay together.

Suppose we gradually heat the liquid. The particles move about more quickly. A few of the more quickly moving particles may jump out of the liquid. The other particles may pull them back but some may escape completely. This escape of molecules is the familiar process of evaporation. If the liquid is made hotter, the particles move more quickly and, at last, *all* are able to break away from each other. They fly off into the air and escape; they have overcome the force of cohesion. The liquid has boiled and changed into a gas!

The particles in a gas are almost completely free from each other. They move about at great speeds (several hundreds of miles an hour), bouncing off the sides of the container and off each other. We might compare a container of gas with a room containing some flies. The flies move all over the room but most of the room is empty. We can soon realise that most of a gas is empty space. A cubic inch of water makes about 1700 cubic inches of steam. The molecules in the cubic inch of water must spread out and "fill" about 1700 cubic inches of space, so 1699 cubic inches of the steam consist of nothing!

We can now easily understand the well-known properties of a gas. A gas always fills its container because the particles are free to move to all parts. If we make the container smaller, there is still room for the particles ; if we make the container bigger, they can move further and spread out. A gas has neither a fixed shape nor a fixed volume. The particles hit the sides of the container and bounce off again. This makes the pressure on the inside of the container. If we make a hole in the side of the container, some of the particles can move through and escape. (This is what happens when you get a " puncture " in your bicycle tyre !) Two gases mix very easily of their own accord. The quickly moving particles of the two gases soon mix together.

We have explained, perhaps rather quickly, the chief differences between solids, liquids, and gases. We see that the idea of particles fits in very well with the actual facts. Has this been a difficult chapter ? We have learned about elements and compounds, atoms and molecules, and the force of cohesion. We shall need to talk about these things many times in this book. If you are not quite sure about them, just look over this chapter again.

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CHAPTER IV

CRYSTALS

SUGAR, as you know, consists of many separate little grains. These grains shine in the light. If you examine them carefully, particularly with a magnifying glass, you see that each has a definite, regular shape. The sides are flat and the edges are sharp. We call such bits "crystals." There are other substances in the home which consist of crystals, or, as we say, are "crystalline." Ordinary salt is crystalline (though the crystals are small), Epsom salts consists of fine-shaped crystals, and washing soda, though sometimes rather powdery, may contain some nice crystals. Certain kinds of rocks are crystalline. Granite, for example, consists of several different kinds of crystals; they make the rock sparkle and shine. Sometimes quite big crystals are found in rocks. The pictures on p. 27 show some of these rock-crystals.

In order to study crystals more fully, we must first learn how they are formed. Most of the following experiments you can try at home. The chemical substances which you need can usually be obtained easily from a chemist's shop. Convenient substances are alum, copper sulphate, Epsom salts, potassium nitrate (saltpetre), and "hypo" as used by a photographer. (This last substance is properly called sodium thiosulphate.) Soda is not a very convenient substance because it tends to turn into a powder.

Half-fill a tin (or other container which you can safely heat) with cold water, add a little solid substance (such as powdered alum or saltpetre), and stir well. The solid dissolves and makes a solution. If you add further small amounts, they, too, dissolve. You can add several extra amounts but, at last, you find that no more can dissolve. The solution is now as strong as it can be. Now add a further small amount of the solid and heat the solution. The extra solid dissolves. Hot water can dissolve more solid than cold water.[1]

Leave the hot, strong solution to cool. What happens? Some of the solid comes out of the solution again. The cold water cannot hold the extra solid which you added. After the solid has settled at the bottom, pour off the liquid and shake the solid on to a piece of blotting-paper. Press the solid with the paper so as to dry it, and then examine it carefully with a magnifying glass. It consists of a mass of small, shining crystals.

You can try this experiment another way. You can start with boiling water and dissolve in it as much solid as possible. Then you can leave the hot solution to cool and proceed as described above.

You can try the next experiment with any of the substances mentioned earlier. First crush the solid into a powder so that it dissolves easily. Make a strong solution with cold water. Pour a little of the solution into a small dish and loosely cover the top with a piece of paper to keep out the dust. Stand the dish in a place where it will not be disturbed for several days. The water of the solution gradually evaporates (dries up). As the amount of water becomes smaller, less solid can dissolve in it. The solid gradually comes out of the solution and appears, as crystals, on the bottom of the dish.

The crystals which are made in this way are usually bigger than those made by cooling a hot solution. The crystals form more slowly because the solid is set free from the solution more slowly. We shall explain later why the size of a crystal depends upon how slowly it is formed.

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[1] This is true of most substances but there are some (e.g. common salt) which do not dissolve much better in hot water than in cold water.

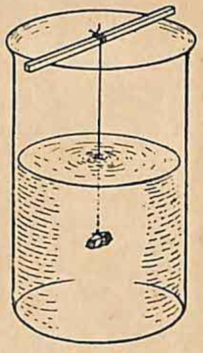
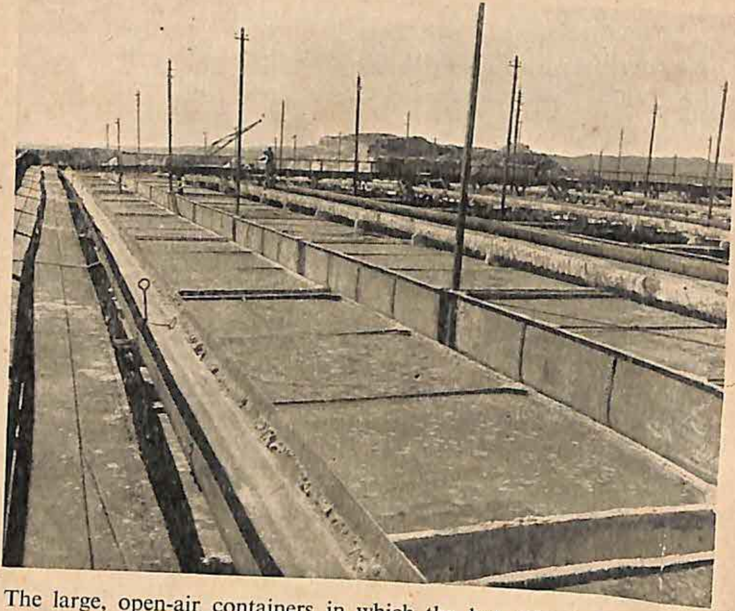


FIG. 6.

It is not easy to make very big crystals. A small, well-shaped crystal, made in one of the above ways, is tied on the end of a piece of thin cotton (or, better, a hair) and hung in a very strong solution of the substance (Fig. 6). Some of the water slowly evaporates and the solid which is set free is deposited on the crystal hanging in the middle. A crystal an inch or more long can be made in this way. You can try the experiment with alum or with copper sulphate. There are two main difficulties. If the solution is not as strong as possible, the crystal on the cotton dissolves and disappears ! If the solution becomes warmer (e.g. because the day is warm), again the crystal may dissolve and disappear. Stand your jar in a place where the temperature will be fairly even—and do not be disappointed if you do not succeed the first time you try.

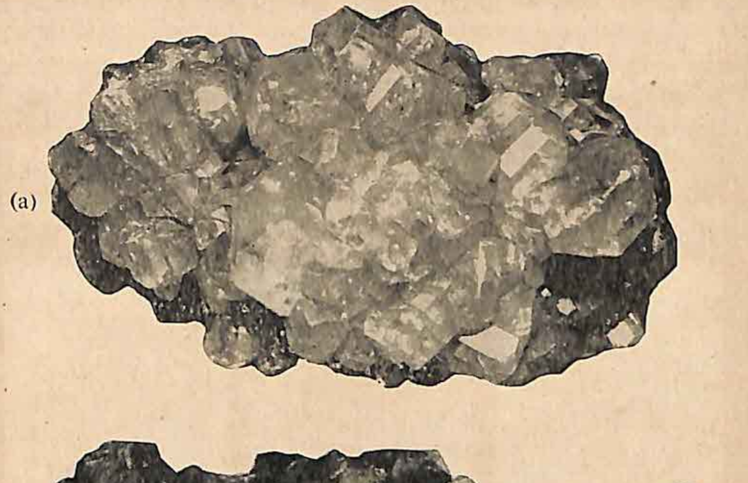
The process of forming crystals from a solution is one way of making solid substances pure. There is an important substance, for example, called Chile saltpetre (sodium nitrate) ; it is found a few feet below the soil in certain parts of South America. The impure rock is dug up, broken into smaller pieces and mixed with water. The saltpetre dissolves but the sand (and other earthy matter) does not dissolve. The solution is run off, heated to drive off some of the water, and poured into big, open containers (see the picture on p. 26). Here the rest of the water evaporates and leaves pure crystals of the saltpetre behind.



The large, open-air containers in which the hot saltpetre solution is allowed to cool. Masses of crystals are gradually formed.

Crystals of Chile saltpetre (sodium nitrate).

(Photographs by courtesy of Nitrate Corporation of Chile Ltd.)

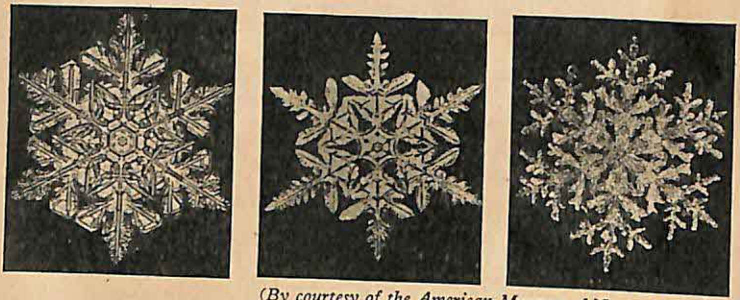


(Crown copyright. From exhibits in the Science Museum, South Kensington)

Some natural rock crystals—(a) sulphur, (b) galena (lead sulphide), (c) quartz.

In our experiments we obtained crystals when a solid was slowly formed from a solution. We can also form a solid by cooling a liquid so that it freezes. If the freezing takes place slowly crystals may be formed. It was in this way that most of the crystals in the rocks were formed. Hot melted rock from deep in the earth came up into holes and cracks nearer the surface of the ground and slowly cooled there.

There is another way in which a solid can form. When a vapour is cooled it usually changes into a liquid, but in certain cases it may turn immediately into a solid.



(By courtesy of the American Museum of Natural History)
Snow crystals (magnified).

Water vapour in the air, for example, may turn immediately into solid ice. Snow is formed in this way. A snow "flake" consists of a mass of very small ice crystals. These crystals are very beautiful. There are many different patterns but all have six sides or six points. The picture shows some of these crystals.

Now that we have learned how crystals are formed, we must study their properties. The most obvious property of a crystal is its regular shape. (We understand, of course, that the shape has been formed naturally; a piece of glass which has been cut to shape is not a crystal.) Fig. 7 shows a few of the many crystal shapes. Notice particularly the cube (*a*) and the six-sided shape (*d*). The shapes (*e*) to (*h*) are more complicated. Notice that (*f*) is based on the simpler shape (*c*) and that (*g*) is something

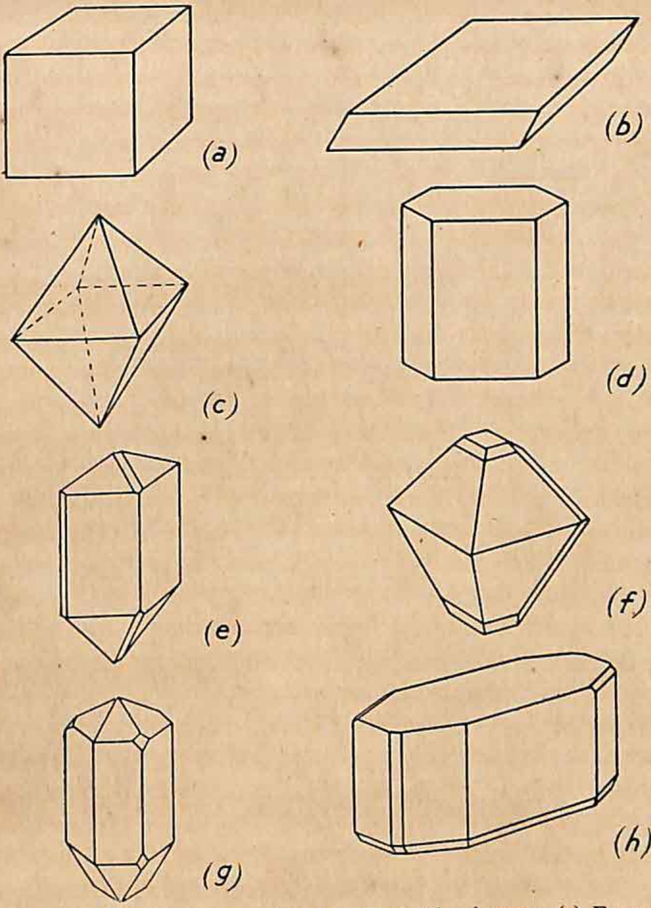


FIG. 7.—Crystal shapes: (*a*) to (*d*) simple shapes; (*e*) Epsom salts; (*f*) sulphur; (*g*) quartz (simplified); (*h*) copper sulphate.

like (*d*) but with a point at the top and the bottom. We commonly say that all the crystals of a substance have the same particular shape, that salt crystals, for example, are always cubes. This is not quite true. As you may have noticed, some salt crystals are brick-shaped; some crystals of Epsom salts are longer and thinner than others. A perfectly formed salt crystal is a cube. It has six faces and the angle where two faces join is a right-angle. If the crystal grows more on one side than another it becomes brick-shaped. But it still has six faces which meet at right-angles. It would be better to say that, for each substance, a crystal has the same number of faces arranged at the same angles.

Many kinds of crystals can be split quite easily in certain directions but cannot easily be split in other directions. A light tap with a knife blade splits a crystal if the blade is held in the right direction. A diamond is very hard. It may take days of work with a grinding machine to cut one in halves but if the diamond is tapped in the right direction it splits fairly easily. We do not often see big crystals and so we are not familiar with this strange property of splitting. (Many substances, e.g. a piece of marble, consist of a mass of crystals joined together in an irregular way and then the substance does not split more easily in one direction than another.)

A crystal, then, has two chief properties: it has a regular shape and it splits much more easily in certain directions than others. Can we explain why it has these properties?

Suppose we arrange some marbles (or some little clay balls) in a pattern on the table. We could arrange them in many ways. Fig. 8 *a* shows a very simple pattern. The marbles are arranged in rows so that each one is at a corner of a square. (The lines show the various rows.) Any marble, like A, which is not near the edge, has 8 other marbles round it: 4 near ones and 4 a little further away. We can easily see that by arranging the marbles in this pattern we can build up a regular shape. In the drawing the whole pattern makes a square. Now suppose you take a knife and " cut " the pattern into two. You could do it very easily if the knife points upwards (from the bottom of the pattern to the top), or sideways, or in either of the directions marked X and Y. If the knife points in other directions you would have to cut into some of the marbles.

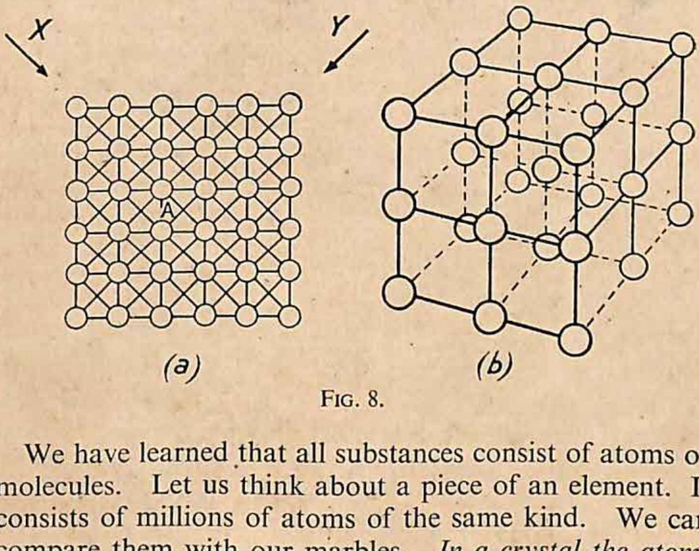


FIG. 8.

We have learned that all substances consist of atoms or molecules. Let us think about a piece of an element. It consists of millions of atoms of the same kind. We can compare them with our marbles. *In a crystal the atoms are arranged in a regular pattern.* Fig. 8 *a*, for example, can represent a pattern of atoms in a crystal. But if a crystal had its atoms arranged like this, it would be only one atom thick—far too thin for us to see. Fig. 8 *b* shows a similar pattern but the atoms are arranged, not on a flat table, but *in space*. The atoms are at the corners of cubes. We can easily see that if millions more atoms are added all round, but still in the proper pattern, the crystal will be a cube. A regular pattern causes a regular shape.

We can also understand why such a crystal will split easily in some directions but not in others.

Patterns need not consist of squares and cubes. You may like to amuse yourself by drawing a pattern in which each " atom " has six neighbours all the same distance away. There is one important pattern in which each atom has four neighbours all the same distance away. You cannot arrange marbles on a flat table in this pattern but you can built it from wax balls joined together by matchsticks. Fig. 9 *a* shows how the balls must be arranged. Now look at Fig. 9 *b*. It seems rather complicated, but, if you examine it carefully, you will see that it is made up of pieces like (*a*) joined together.

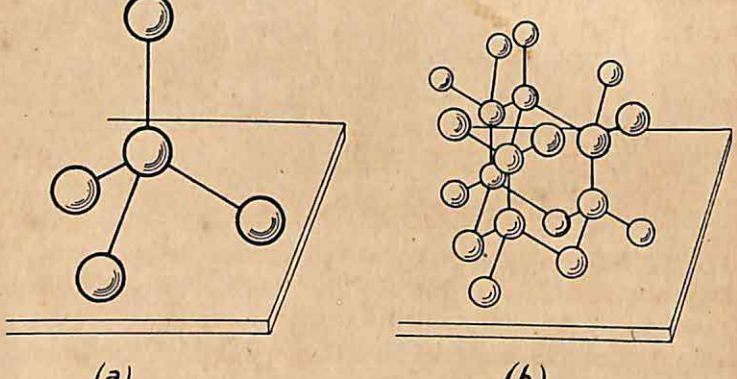

(a) (b)

FIG. 9.

Fig. 9 *b* shows the arrangement of the atoms in a diamond. A diamond consists of the element carbon. In many carbon compounds it is found that a carbon atom is joined to four other atoms (see methane and alcohol in Fig. 5). We can say that a carbon atom has four strong joining points. In a diamond crystal, each carbon aton is strongly joined to four other carbon atoms. It is these strong joins which make a diamond so hard.

A compound consists of molecules and each molecule consists of several different atoms joined together. We must not think of a molecule as a ball; it is more like a number of balls joined together. In the pattern in the crystal, the molecules are not only in certain positions but must be arranged to point in certain directions. The patterns are therefore very complicated.

Let us think what happens when a crystal is made. The solid is being formed; the atoms (or molecules) are coming together to form a solid mass. If the atoms are all set free at once, so that they come together quickly, they have not time to arrange themselves into one big pattern. Little groups may form smaller patterns; we get a mass of many little crystals. But if the solid forms slowly, the atoms have time in which to arrange themselves and we get one big crystal.

By now you may be wondering why some substances, such as salt and sugar, are always crystalline while other substances, such as rubber and hair, are never crystalline. A substance which is not crystalline is said to be "amorphous" (which means "without shape"). Careful examination with a microscope shows that many solids are really crystalline although the crystals are too small for us to see with the ordinary eye. Some powders, for example, are really crystalline. Glass is probably amorphous (though it is not certain that there is *no* arrangement of the molecules). The most important amorphous substances are those of which animals and plants are made (such as starch, hair, fat) and materials made from them (such as paper, cotton, glue). As we shall read in Chapter XIII, these substances consist of very big, complicated molecules. We can understand why they do not form crystals: the molecules are too big and awkward to arrange themselves into patterns.

Metals are rather strange solids. We might think that they are amorphous. We cannot see crystals in a bar of metal. It is possible, however, to show that metals consist of very small crystals. A small piece of a metal is first very brightly polished and then dipped in a chemical solution (e.g. a weak solution of nitric acid in alcohol). When the metal is now examined under a microscope, the surface is seen to be marked off into irregular shapes.

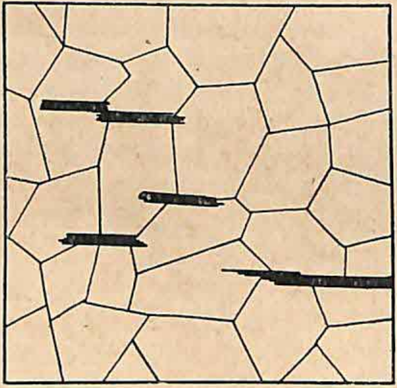
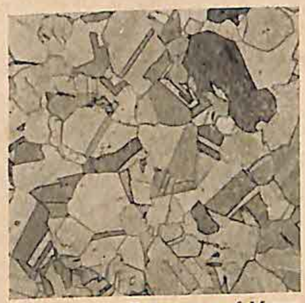


FIG. 10.

These are shown very simply in Fig. 10 (the thick lines represent impurities in the metal); you can also see them in the picture. Each of these shapes is a metal crystal. These crystals are different from the crystals which we have been reading about earlier in the chapter for they do not have regular shapes. *We call them crystals because the atoms in each are arranged in definite patterns.* The whole piece of metal consists of thousands of such crystals stuck together.

We called this chapter "Crystals." We could have chosen another, equally good title. We could have called it "The Patterns of Atoms and Molecules in Solids," for as we have learned, it is the pattern which gives a crystal its special properties.



(By courtesy of Messrs. Hadfields Ltd.)

Microscope photograph of a piece of nickel-chromium steel showing the crystal grains.

CHAPTER V

POROSITY AND CAPILLARITY

WE sometimes use a sponge when we wash ourselves. It can soak up a lot of water and when we press it the water comes out again. We know why a sponge can soak up water. It has many small holes and passages inside it. The water fills these spaces. If you put a piece of white chalk in a saucer of ink for a moment or two, and then take it out and break it across, you find that some ink has soaked right into the middle of the chalk. In a similar way, a lump of sugar can soak up a liquid (e.g. ink, water); so can a piece of brick. The pieces of chalk, sugar, and brick have holes in them like a sponge, but these holes are much smaller and we cannot easily see them.

The very small holes in materials such as chalk, brick, etc. are called "pores." We use the same name for the small openings which we can see in our skin when we examine it through a magnifying glass. A material which contains many pores is said to be "porous." Chalk and brick are porous materials. Other well-known porous materials are blotting-paper, cloth, and dry soil.

Suppose we take a few glass jars, fill one of them with stones, another with peas, and a third with small seeds (e.g. wheat grains, carrot seed). We can tap the jars to make the stones (peas, seeds) get as closely together as possible. But we cannot completely *fill* the jars; there are little spaces between the stones (peas, seeds). The spaces between the small seeds are smaller than those between the larger stones. Whenever a material is made up of separate little bits which do not fit together exactly, there must be spaces between the bits. Such materials obviously are porous. Soil, for example, is made up of many small particles of rock. Chalk and brick are made up of particles (crystals or groups of crystals) loosely stuck together; cotton, cloth, and rope are made up of fibres. We can usually see the pores in these materials if we use a microscope, or even a magnifying glass, but, in any case, we know that they are there because the materials can soak up water.

You might not think that metals are slightly porous. We store water and oil in metal containers. Water is often made to flow along lead pipes but it does not soak through the lead. About the year 1610 the scientist Francis Bacon made a hollow lead ball, filled it with water, and carefully closed up the hole. He then hammered the ball so as to try to compress the water. Water came out all over the surface of the ball like drops of dew. It had been pressed through the very small pores in the lead. A few years later it was shown, in a similar way, that silver and gold are slightly porous. Actually all materials are slightly porous, for there are spaces between the atoms and molecules of which they are made, but these spaces are very small.

In Chapter II we learned how to use a piece of blotting-paper to separate a solid from a liquid. When we poured a mixture of chalk and water into a blotting-paper cone, clear water ran through but the particles of chalk were left behind. We made use of the porous nature of the paper. The water passed through the pores but the particles of solid were too big to pass through. But we cannot, in this way, get back a solid which is *dissolved* in water. The particles of a dissolved solid are so small that they can pass through the pores.

When we separate an undissolved solid from water by passing the mixture through a porous material we say that we "filter" the water. The process is called "filtering." A piece of apparatus used for this purpose (like our blotting-paper cone) is called a filter.

Filtering is a very important process for we depend upon it to make water fit for drinking. Thousands of gallons of water are used every day in a large town (we do not drink it all !) and all this must be filtered to take out particles of impurities which may be floating about in it. A town's water supply sometimes comes from a great lake. The water is filtered by a thick bed of sand (Fig. 11).

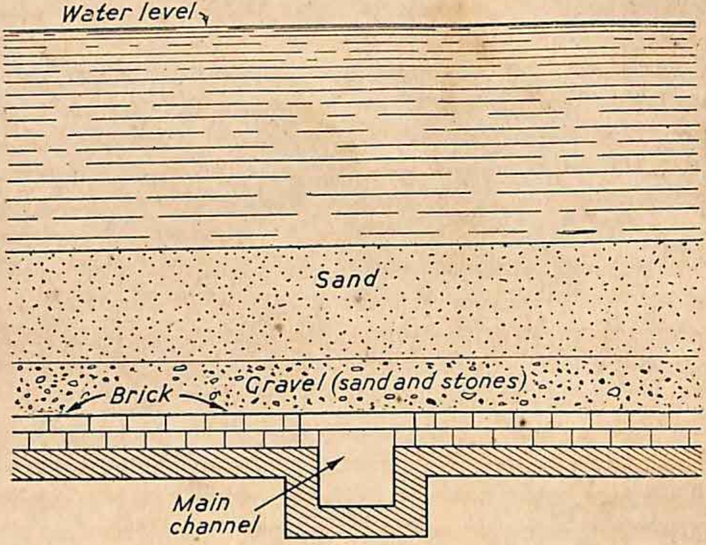
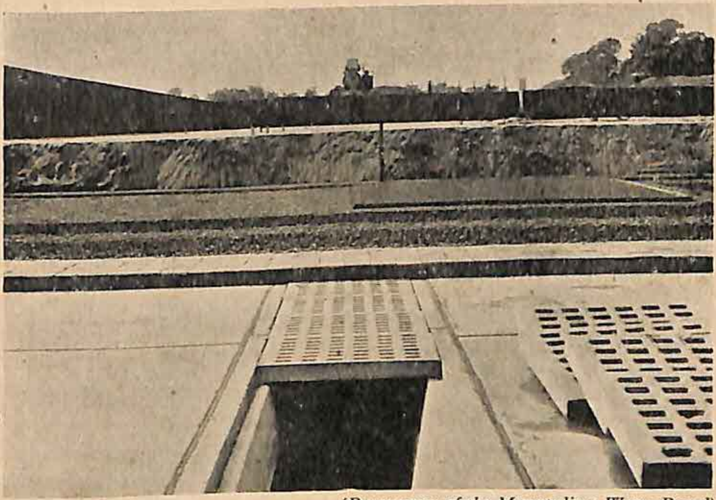


FIG. 11.

There are several filter-beds at a "waterworks" so that, while some are being used, others can be cleaned out and fresh layers of sand put in. You can try an experiment to test this way of filtering water. Fig. 12 shows a tall tin with holes in the bottom. First, some small clean ston



(*By courtesy of the Metropolitan Water Board*)

A sand filter-bed during construction. Notice the layers of sand and the channel at the bottom.

are put in the tin, then a layer of stone "chippings" (little bits broken off stones), and then a layer of sand. Make some muddy water by shaking up a little soil with some water and pour it in the top of your filter. Collect the water which runs through. Has the filter taken away most of the mud? In an actual waterworks, of course, the water is not so dirty as that used in this experiment and the sand-bed is much thicker. After the water has been filtered, it is treated with chemicals to kill disease germs.

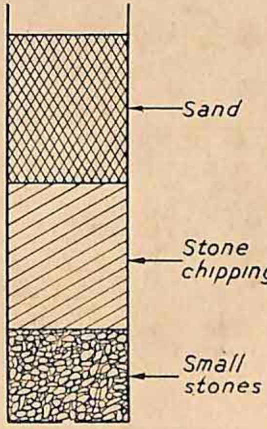


FIG. 12.

Soldiers in camps must sometimes make their own filters. A good filter can be made by packing sand and small stones in a wooden barrel. When on the march, a soldier may have to be content with filtering muddy water through a canvas bag or even through his hat !

Much of the rain which falls on the earth does not immediately drain away in streams and rivers but sinks into the porous rocks. Some rocks and sand and soil are very porous. Grass, trees, and other plants depend upon the rain-water which sinks into the ground. They could not live if the ground were not porous. Water often continues to sink into the ground until it comes to a layer of rock through which it cannot pass. Look at Fig. 13. It shows a hillside made mostly of sand but with a layer of clay deeper down. The layer of clay comes to the surface of the ground near the bottom of the hill. Water cannot easily pass through a layer of clay. It collects above the layer, filling the spaces between the sand particles. If a well is made to reach the wet sand, water collects in it.

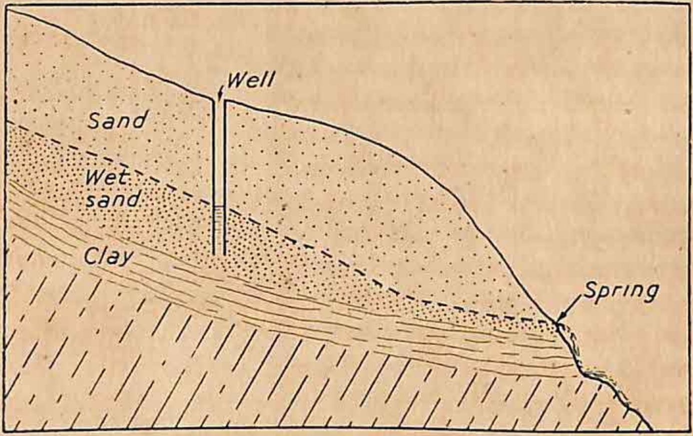


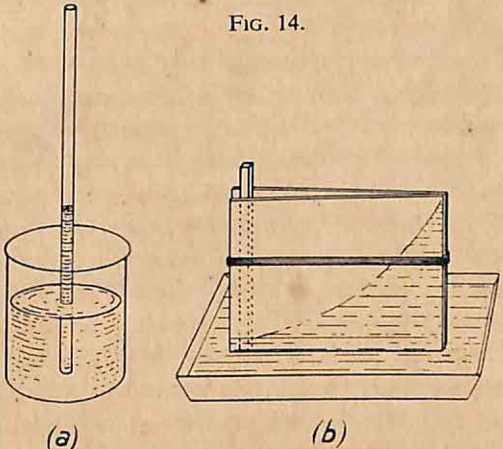
FIG. 13.

The clay-layer may be on the slope. Then the water runs "downhill." If, as in the drawing, the clay-layer comes to the surface, water comes out of the ground just above the layer. This is a spring. Spring water is usually very pure. It has been filtered by the porous rocks above the clay.

If you hold a piece of blotting-paper with one corner dipping into some ink, you notice that the ink does not merely fill the pores of that corner of the paper. The ink is soaked up higher into the paper. In a similar way a brick can soak up water. We must examine this effect.

Fig. 14 *a* shows a narrow glass tube standing in a jar of water. We notice that the water has risen in the tube; its level inside the tube is higher than that of the water in the jar. If we test a number of tubes of different sizes we find that the water rises highest in the narrowest tube. We can show the same effect in a slightly different way. Take two small, clean glass plates and fasten them together with string or with a rubber band. Put a thin strip of wood

FIG. 14.



between them near one edge so that they are opened to a very narrow V shape (Fig. 14 *b*). Hold the glass plates, as shown, in a shallow dish of water. The water rises between the plates. It rises least near the piece of wood, where the plates are furthest apart, and highest at the other edge where the plates are closest.

We call this effect "capillarity." The word *capilla* is the Latin word for *hair* ; the effect is best seen in thin, hair-like tubes. We cannot, at this stage, explain why the effect takes place. It is connected with a property of liquids called surface tension about which we shall read in Chapter XI.

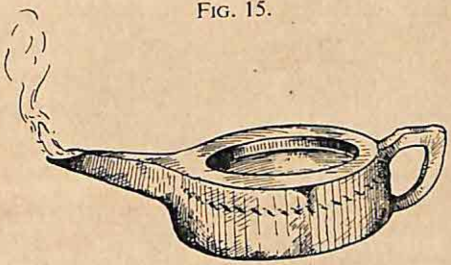
Fig. 14 *a* shows just one tube standing in water. Obviously we can stand a number of tubes side by side. Water will rise in all of them. The small pores in a porous material (such as blotting-paper) are joined together ; they form many irregular hair-like tubes. Water rises up these tubes just as it rises up a glass tube. A porous material therefore "soaks up" water.

Hang a strip of blotting-paper with one end dipping in some ink. The ink rises up it and, if the strip is long enough, you see that it rises to a certain, definite height. The height to which a liquid rises depends upon the size of the pores and the nature of the liquid. Hang a piece of sewing cotton with one end in some ink. How does the height to which the ink rises compare with the height in blotting-paper ? What can we say about the sizes of the pores ? Try similar experiments with blotting-paper, cotton, and rag dipping into coloured water, olive oil (or palm oil), and lamp-oil. Which liquid rises best ? Notice that the olive oil, obtained from a plant, does not rise well.

We make use of the capillarity effect in porous materials every time we use a piece of blotting-paper to dry up some ink, a cloth to dry our faces, a rag to wipe up some liquid.

The use of a wick in an oil-lamp is a very important example. Oil-lamps have been found in the burying-places of Egyptian kings who lived long ago. The early lamps, in which some kind of plant-oil was burned, were shaped like shallow cups with spouts (Fig. 15). The wick was made from the inside of the stem of a tall grass-like plant. It passed down the spout and floated in the oil. The oil rose up the wick by capillarity. The wick in a modern oil-lamp is made of woven cotton. We usually burn paraffin (kerosene) in an oil-lamp now because it rises more easily up the wick than plant-oil and makes a better flame, but plant-oil is still used in some parts of the world. There is also a wick in a candle. The wax is melted by the flame and rises up the wick to burn at the top.

FIG. 15.



We must not think that the capillarity effect in porous materials is always an advantage. We cannot stop a porous material from soaking up a liquid and this is often a disadvantage. Bricks are porous. The bricks at the base of a house take up moisture from the ground, and if this is not stopped it would spread upwards and make the walls of the rooms damp. A good builder puts a " damp-proof " layer in the walls about a foot above the ground (Fig. 16). This is a layer of material through which water cannot pass. It may be made of slate, asphalt, or special glazed brick (see below).

A hut made of wood does not last so long as a house built of bricks. Wood contracts, bends, and cracks in

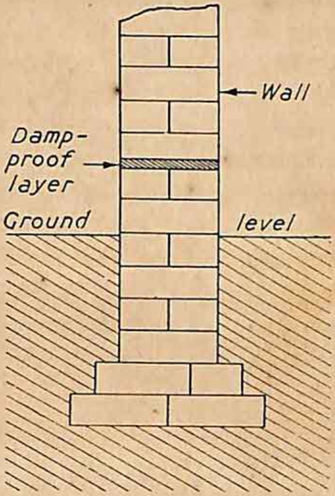


FIG. 16.

hot weather because it loses moisture. In rainy weather it soaks up water, because it is porous, and then it swells so that windows and doors stick in their frames. Further, the moisture causes the wood to rot. We often try to preserve the wood by soaking it in creosote—an oily substance obtained from tar. An interesting example of this is found on the railway. The rails are fixed on " sleepers " which are half-buried in the ground. The sleepers are often made of wood[1] and although the ground is made so that water drains away, they are sure to become wet at times. Before wooden sleepers are laid, they are put in a closed container and all the air pumped out. This leaves the pores in the wood quite empty. Then warm creosote is poured in. It is drawn into the pores. Sometimes air is pumped into the container to force the creosote further into the pores. Sleepers treated in this way last for many years.

Although all materials are really slightly porous, it is convenient to say that materials are " non-porous " if water cannot soak into them. Metals, glass, and rubber are non-porous materials. We use glass for bottles, metals for various kinds of containers, and rubber for bicycle and motor-car tyres. The air in a tyre escapes only very slowly through the rubber. Obviously we can make a porous material non-porous if we can close up, or fill up, the pores. This is done in the making of several well-known things.

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[1] In places where white ants might destroy wooden sleepers, or floods quickly rot them, metal sleepers are used.

Cups, dishes, pots, bricks, etc. are made from clay. Damp clay is soft and can be pressed into the shape which is needed. When it is heated in a furnace it becomes hard and firm, but it is still porous. But vessels for holding water, such as cups and pots, must be non-porous. It was about 400 years ago that men discovered the modern way of covering the surface of clay vessels with a glass-like material so that they become non-porous. We call the process "glazing." Compare the rough surface of an ordinary brick with the smooth, glazed surface of a cup. The thing to be glazed is dipped in a mixture of

(By courtesy of Messrs. Josiah Wedgwood & Sons Ltd.)

The "dipping" process in the glazing of pottery.

certain finely ground rocks (containing sand) and water, and then re-heated in a furnace. The sand melts and forms the glaze. Sometimes the rocks are mixed with the clay before the thing is shaped.

Have you ever tried to write with ink on a piece of blotting-paper ? The ink spreads in the porous paper so that you cannot see your writing clearly. For the same reason, you cannot write well on a piece of newspaper. Good writing paper is " sized." It has been coated with " size "—a kind of thin glue—and so given a hard, non-porous surface. A builder often uses size to fill up the pores in the plaster walls. This stops his paint and other colouring materials from soaking in.

Cloth and similar woven materials are very porous. To make them " water-proof " (so that water cannot soak through them), the pores must be filled up with a non-porous substance. Tar is a substance much used for this purpose. Coarse sack-like material treated with tar is called " tarpaulin." It is used to cover the goods in open railway trucks, to cover over the openings in a ship's deck in rough weather, and by farmers to keep their store of hay dry. A similar material (tarred felt) is sometimes used on the roofs of huts. Rubber is another material used for making cloth water-proof. A man named MacIntosh invented a method by which the pores in cloth could be closed by a thin layer of rubber. We often call water-proof coats " mackintoshes " in memory of him.

Now look round for other examples of porous materials —at home, in the street, in big buildings. You will find that there are many. Try to think, in each case, whether the porous nature of the material is an advantage or a disadvantage.

CHAPTER VI

STRENGTH WITH FIRMNESS

IF you want to pull along a heavy load, would you choose a piece of cotton or a rope? Of course you would choose the rope. Why? The rope, you say, is stronger; it is less likely to break when we pull on it. There are many times when we need to use materials which are strong. Iron hooks and chains are used for joining railway trucks, a horse pulls a cart by means of leather straps, wire ropes are used on a crane. Strength is clearly an important property. A man who builds a house, or a bridge, or a motor-car, must also use strong materials. But he would not use rope or leather. Why not? He needs materials which are both strong and firm. The metal bars in a bridge, for example, must not bend and lose their shapes. The walls of a house must be able to support the weight of the roof and withstand the force of the wind without bending or breaking. We often need materials which are both strong and firm. We shall read about such materials in this chapter.

Fig. 17 shows a weight hanging on the end of a piece of wire. The weight pulls downwards on the wire. Unless the weight is very big, the wire can withstand this pull; it supports the weight. What happens inside the wire? The metal is made up of atoms (in crystal grains). They are held together by the force of cohesion. When the weight pulls on the wire, the atoms are pulled further apart, against the force of cohesion, and so the wire becomes slightly longer. In other words, the wire stretches. When the weight is taken off, the force of cohesion pulls the atoms back into their proper places. We see, then, that there are forces inside the wire which try to stop the atoms from being pulled further apart. At the lower end of the wire these forces are pulling upwards and so hold the weight; at the top of the wire they are pulling downwards on the support.

When a wire or bar is pulled so that forces are set up inside it which try to withstand the pull, we say that there is a "tension" in the wire or bar. There is a tension in the wire drawn in Fig. 17. There is a tension in a piece of stretched elastic and in a piece of string tied tightly round a parcel. We sometimes say that the wire, bar, string, etc., is "in tension." The tension, we understand, is a set of inward forces caused by the force of cohesion.

Now suppose, in Fig. 17, further weights are tied to the lower end of the wire. The pull on the end is stronger. The atoms are pulled further from their places but the force of cohesion withstands the increased pull. If more weights are added, the atoms begin to slide past each other, and, at last, the force of cohesion can no longer hold them together. The wire breaks. When we speak of the strength of a material, we are usually thinking of its strength to withstand this kind of force, i.e. a force which pulls the material longways. In order to be clear that it is this kind of strength which is meant, an engineer calls it the "tensile strength" of the material.

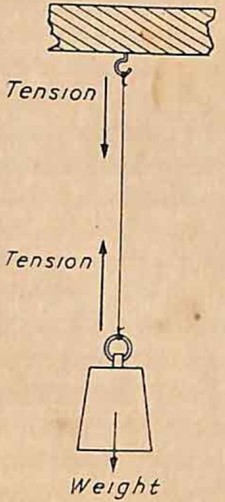
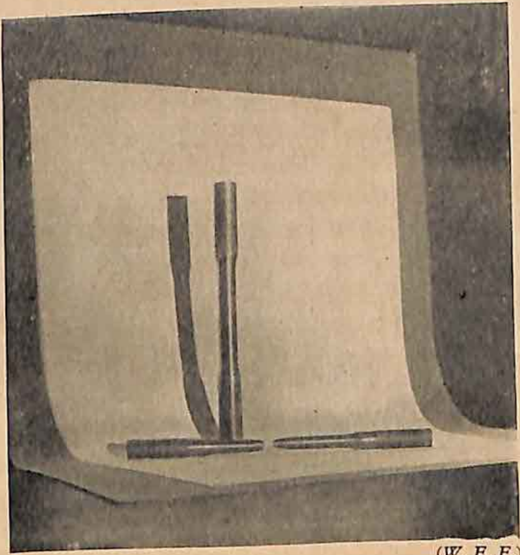


FIG. 17.

You can make a rough measurement of the tensile strength of a thin wire in the following way. Tie a bucket to one end of the wire and tie the other end to a firm support. The bucket should hang so that it is not more than about 2 inches from the ground. Pour water into the bucket, a pint at a time, until the wire breaks. As a pint of water weighs 1¼ lb, you can calculate the weight of the water which you poured in, and, if you add in the weight of the bucket itself, you can find the total weight which breaks the wire.

Let us see how an engineer measures the tensile strength of a metal bar. He may need to know, for example, the strength of the bars with which he intends to build a bridge. He cannot conveniently test the actual bars which



(*W. E. F.*)

Mild steel bars for tensile tests. *Upright:* a bar made with an area of cross-section of ½ square inch. *Bottom:* a bar of cross-section ¼ square inch which has been broken in a testing machine.

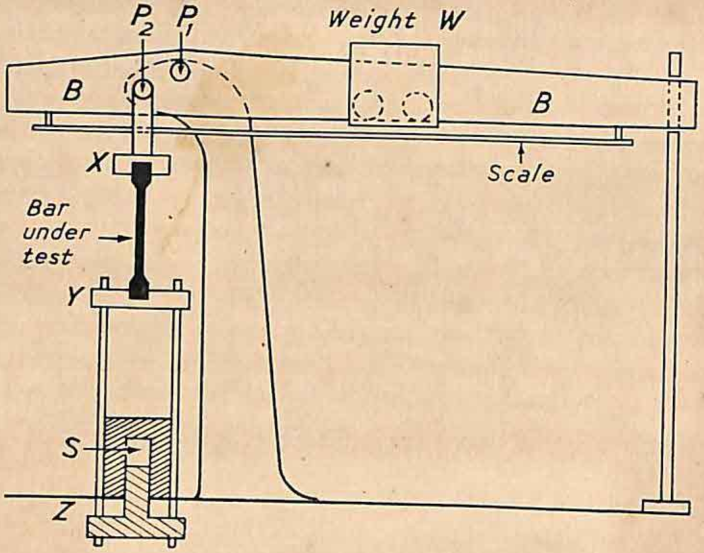


FIG. 18.

he will use, for they are probably too big, so he tests a smaller bar made of the same material. When he knows the strength of the smaller bar he can easily calculate the strength of the bigger bars. Fig. 18 is a simple drawing of the kind of testing machine which he uses. The piece of metal under test may be about 9 inches long and the slightly narrower middle part about ½ inch thick.[1] Two marks are made on the bar a certain distance apart (e.g. 2 inches). The bar is held between the two parts X and Y. There is a big beam B across the top of the machine. It can turn, like a lever, about the pivot P_1. The part X, to which the bar is fixed, hangs from the beam at the pivot

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[1] The bars are made so that the *area* of cross-section is exactly 1 square inch, or ½ square inch, or ¼ square inch. A round bar of thickness 0·564 inch has an area of ¼ square inch.

P_2. This pivot is only a short distance (e.g. 3 inches) from the pivot P_1. There is a big weight W on the other side of the beam.

The bar under test is stretched, and at last broken, by pulling the part Y downwards. This is usually done by water-power. Notice the lower part Z to which Y is joined. It is forced down by pumping water into the space S. In this way very strong forces can be obtained. When the bar is pulled, the left-hand side of the beam moves down. The weight W is moved along the right-hand side of the beam until the beam balances. Then from the position of the weight, as measured on the scale below it, the actual pull on the bar can be calculated.

The force on the bar is gradually made bigger. The bar stretches. The amount of stretch can be found by measuring the distance between the two marks which were made on it. At first the bar only stretches slightly but, after a pull of certain strength, it stretches much more. The atoms are now beginning to slip from their places. At last the bar breaks.

The strength of the force needed to break a bar depends not only on the nature of the material but also on the thickness of the bar. Imagine a bar whose cross-section (shape as seen if cut across) has an area of 1 square inch. (A round bar 1⅛ inch thick has a cross-section of 1 square inch.) An engineer states the tensile strength of a material as the force which breaks a bar with this cross-section. Thus the tensile strength of mild steel, as used for bridges, is about 25 tons per square inch. Notice that, with this knowledge, the strength of any mild steel bar can be calculated. Thus a bar of cross-section 2 square inches has a strength of 50 tons, and so on.

Metals are the strongest solids and steel is the strongest metal. The finest kind of steel can withstand a pull of over 100 tons per square inch. Mere strength, however, is not the only desirable quality in a metal. For many purposes the material must also be able to bend without breaking. A material which withstands bending without breaking is said to be " tough." The toughness of steel depends upon the amount of carbon it contains (steel is iron which contains a small amount of carbon) and how it has been heated. Hold a knitting-needle in a fire until it is red-hot and then draw it out gradually so that it cools very slowly. When it is cold you can bend it into the shape of a U. It is very tough. But if you draw the needle out of the fire quickly and cool it by putting it in some cold water, it breaks immediately you try to bend it. Fine, hardened steel is not so tough as ordinary " mild " steel, although it is stronger. So for most building purposes mild steel is the more useful metal. When a very tough material is needed, as in the chains which join railway trucks, wrought iron (almost pure iron) must be used. This, however, is not so strong as mild steel.

Many parts of buildings, and some parts of machines, do not have to withstand a pull but must be able to support a weight. Think of the walls of a house. They must support the weight of the roof. Fig. 19 shows a post with a weight on the top of it. The weight presses downwards and tends to compress the post. The particles of which it is made are pushed closer together. This time there are forces within the material which push *outwards* and try to push the particles back to their proper positions.

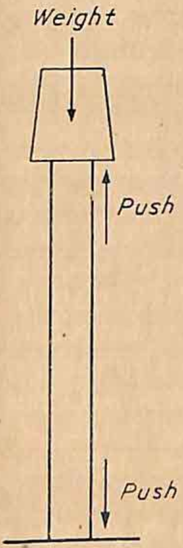

FIG. 19.

There is an upward push at the top of the post, supporting the weight, and an downward push at the bottom of the post pressing on the ground.

It is not easy to measure the strength of a material which is compressed. Many materials give way to forces which try to compress them, not by breaking, but by bending. Take a piece of paper and hold one end in each hand. Slowly bring the hands together so as to try to compress the paper. The paper gives way by bending. Then, again, a soft material like clay can withstand strong compressing forces without breaking. The material gives way by becoming shorter and fatter, and we cannot really say that it breaks. Some materials, however, break when we try to bend them. We say that they are brittle. Glass is obviously a brittle material. Such materials break under strong compressing forces. That is why cups and plates, for example, break when we drop them on a hard floor.

Many materials which cannot withstand a pull can withstand compression. Stony materials, like brick, building-stone, concrete (cement), can bear heavy loads on the top of them but cannot withstand strong pulling or bending forces. Very hard stone like granite can withstand a compressing force of about 8 tons per square inch ; concrete has a strength of about ½ ton per square inch. Big buildings, such as the " sky-scrapers " in America, are often made of concrete strengthened with steel bars inside. A building of concrete alone can withstand a great weight but may break if the wind bends it sideways. Steel alone is far too heavy and costly. But a " ferro-concrete " (steel inside concrete) building is very good. The concrete supports the loads and the steel withstands any bending or pulling.

Let us examine the problems of bending in more detail.

A building, bridge, crane, etc., will not be strong and firm if parts of it bend. Support a thin, wooden ruler at its two ends and hang a weight from its middle. It bends so that the middle is lower than the ends. If the weight is increased, the ruler bends more and, at last, breaks. What kinds of forces are acting on a bar which is bent in this way? Look at Fig. 20 *a*. It shows a strip of wood with cuts, made by a saw, in the top and bottom surfaces. These saw-cuts are all the same thickness. In Fig. 20 *b* the strip has been bent. Look at the saw-cuts. They are narrower on the top surface on the inside of the bend, but are opened out on the bottom surface on the outside of the bend. We see that the top part of the strip has become shorter; it has been compressed. The bottom part of the strip has become longer; it has been stretched. When a bar bends, therefore, the parts inside the bend are compressed and the parts outside the bend are stretched. The bar breaks if the material cannot withstand either the pushing (compressing) or the pulling (stretching) forces.

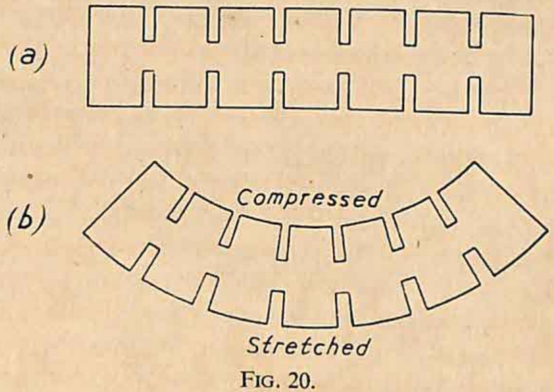

FIG. 20.

The big steel bars used in building bridges, roofs of railway stations, etc., are usually called "girders." Most girders, you will find, have the shape shown in Fig. 21. We call them **I**-shaped girders. Notice that they are wider at the top and bottom. Such bars are less likely to bend than ordinary bars because they are wider, and therefore stronger, where the compressing and stretching forces of bending are greatest. A railway line is made of similar bars for the same reason.

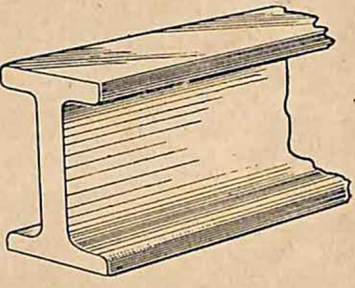
FIG. 21.

The problems of bending are very important in the building of bridges. A bridge is supported at its two ends [1] and must be able to carry a load at its middle. This load is the weight of the trains, cars, people etc. which cross the bridge and the weight of the bridge itself. Bridges have been built of many different kinds of material—wood, stone, brick, metal—and are of many different kinds and patterns. Let us study some of the ideas which are used in building a modern steel bridge.

First try this simple experiment. Take a long strip of wood, about an inch wide and $\frac{1}{4}$ inch thick, and support it at its ends as shown in Fig. 22 *a*. Hang a weight from its middle (Fig. 22 *b*). The strip bends. Now support the strip on its narrow edge and try the experiment again (Fig. 22 *c*). With the same weight, the strip hardly bends at all. We see that a bar which is thick (in the direction in which bending might take place) can withstand bending forces better than one which is thin.

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[1] Some bridges consist of several " spans," the ends of each span being supported on pillars built in the river etc. which the bridge crosses.

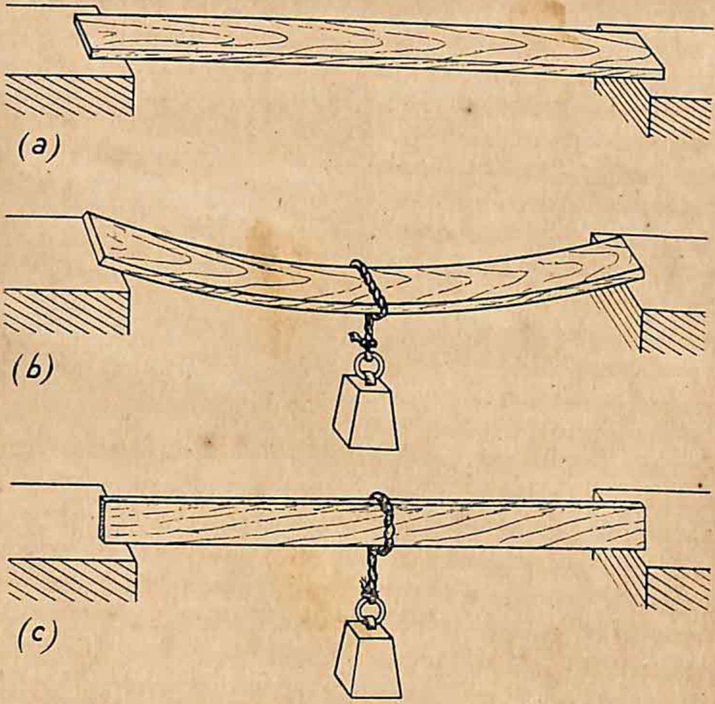


FIG. 22.

In building a bridge, therefore, we do not merely make a flat part over which the trains, people, etc. can pass ; we make upright sides to the bridge so that, at the sides at least, it is thicker. In a small bridge, these sides can be built from steel plates (sheets). A metal plate, standing on its edge, is like a girder which is very thick in the upward direction. These plate-girder bridges are very common on railways. They are used for crossing roads, small rivers, and, in big cities, other railway lines.

A plate-girder bridge is not suitable for crossing a wide river. The plates forming the sides would have to be thick and tall to stop bending and then the bridge would be heavy and costly. The sides of a big steel bridge are therefore made of bars forming a framework (see the picture on p. 58). Fig. 23 shows a very simple framework bridge. The framework is made of five bars AD, DC, CE, EB, DE, extra to the main part of the bridge AB.

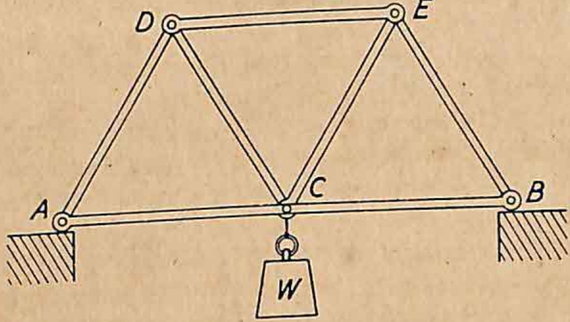


FIG. 23.

Such a framework is light in weight but very strong. It is strong because it consists of triangles. Suppose we loosely join four bars together to make a square (Fig. 24 *a*). We can fairly easily push the square out of shape (Fig. 24 *b*). But if we join three bars to make a triangle (Fig. 24 *c*), we cannot push it out of shape without bending or breaking one of the bars. The picture shows the Ava Bridge in Burma, one of the largest girder bridges in the world. Each " span," from one pillar to the next, consists of a framework of triangles.

Before a large steel bridge is built, the engineer must carefully calculate the force that each girder will have to bear. Then he can calculate how thick the various girders

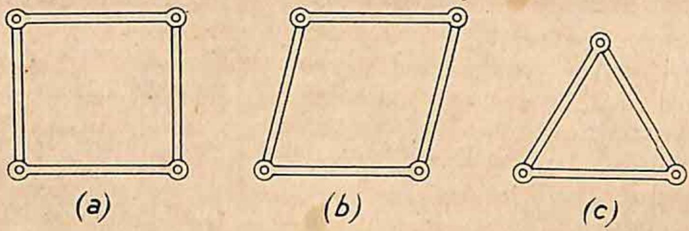


FIG. 24.

must be. About two years were spent in making calculations before the great Sydney Bridge was built in Australia. Some of the girders must withstand pulls and some must withstand compression. Look again at Fig. 23. The weight W represents the load on the bridge due to trains, people, etc. What might happen if the girder DE broke? The weight might cause the bar AB to bend so that the corners D and E come closer together. The girder DE, therefore, helps to hold D and E apart. It pushes outwards in order to stop itself from being compressed. We call such a girder a "strut." Now suppose either or both

(E. N. A.)

The Ava Railway Bridge across the Irrawaddy River, Burma.

of the girders DC, CE broke. What might happen ? The weight might bend AB so that the point C drops. The girders DC and CE are helping to hold up the point C (and thus the weight W). There are pulling forces in these girders ; they are in tension. We call such girders " ties."

There we must leave our story of strength with firmness. We have learned of strength to resist a pulling force, of strength to resist a pushing (compressing) force, and of some ways of resisting bending forces. When you see a big building, a bridge, a crane, a machine, try to think how it has been made so that it is strong and firm.

CHAPTER VII

STRENGTH WITH FLEXIBILITY

WE often use a piece of string for tying up a parcel. What are the particular properties of string which make it so suitable for this purpose? We tie the string tightly round the parcel; it is in tension. It must be able to withstand a strong pull, or we have now learned to say, it must have a high tensile strength. But the string also has another important property. We can bend it easily; we can wrap it round the parcel as we wish. A piece of material which bends easily is said to be "flexible." The string has the two useful properties of strength and flexibility.

In our daily lives we make great use of materials which are both strong and flexible. We use string for many purposes. When we want a stronger material we use rope. Rope is used for holding up the sails of a ship, for lifting a bucket from a well, for tying small boats to the shore. Ropes strengthened by metal wire are used for tying up bigger ships, for lifting heavy things with a crane, for lifting the "cage" in a mine. Cotton is another strong, flexible material. We use it for sewing our clothes. And even our clothes are woven from cotton or similar materials. On the road we see a horse pulling a cart by leather straps. No doubt you can think of many more examples of uses of strong, flexible materials.

We realise, of course, that these materials can withstand a strong pull but give way to a small push by bending. We can hang up a weight by a piece of string but we cannot make the string stand up straight and support a weight at the top! The string cannot, in fact, even support its own weight. These materials have a high tensile strength but cannot withstand even the smallest compression.

Most metals, as we read in the last chapter, have high tensile strengths. But a thick metal bar is not very flexible. A thin bar is more flexible. A wire, of course, is a very thin bar. Wires can be made of most metals—iron, steel, copper, brass, silver, and so on. We shall read in Chapter X how wires are made. A steel wire is very strong. Its tensile strength is actually increased in the process of making the wire but this means, of course, its strength *according to its thickness*. If we twist a number of wires together we make "wire-rope." This is very strong and yet fairly flexible. The strongest, thickest kinds of wire-rope (usually called "cables") are built up by twisting together simpler kinds of wire-rope, often round a middle part made of a different material. Fig. 25 shows a cable made by twisting six wire-ropes, each consisting of seven wires, round a hemp middle. (Hemp is the material from which ordinary rope is made.) Wire-ropes and cables are used in cranes, for tying up great ships, for pulling trucks in a mine, and so on. The picture on p. 62 shows another use of a cable. The trucks hang from, and run along, the strong cable supported on posts. Such an "aerial railway" is very useful when the making of a proper railway would be too expensive. It is often used, for example, for carrying rock and metal ore from a mine to a ship or to a proper railway.

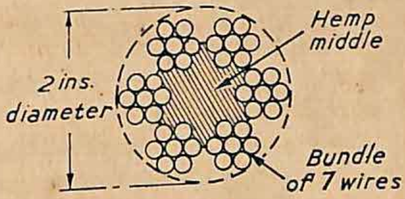
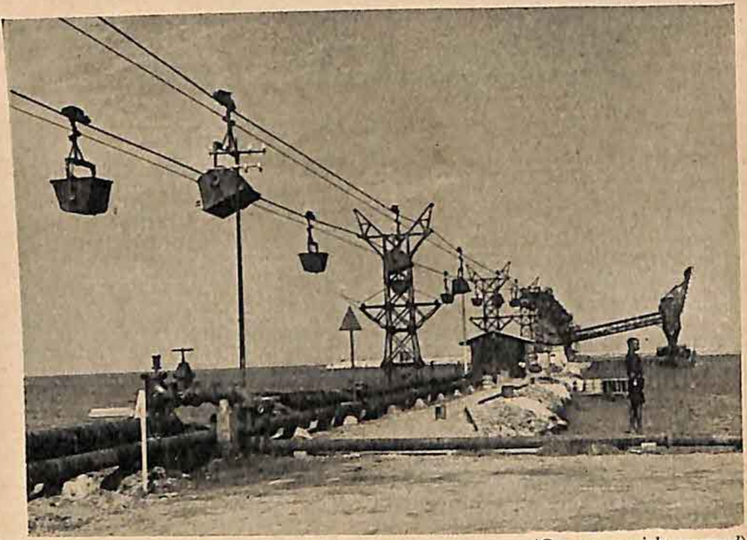


FIG. 25.



(*Crown copyright reserved*)

The overhead " ropeway " at Takoradi (Gold Coast) by which aluminium ore is carried to the ships.

There are other kinds of cables made for special purposes. Most of you know the cables, supported from tall posts, which carry electricity from one town to another. These cables are made of aluminium with a steel wire in the middle. Aluminium is used because it carries electricity well and is light in weight. But it is not strong. So the cable is strengthened by putting a steel wire in the middle. Then there are the cables which are laid on the bottom of the sea, from one country to another, to carry telegraph and telephone messages. These are very complicated. They consist chiefly of three parts : copper wires for carrying the electricity, covers of rubber and other materials to keep the electricity in and to protect the cable, and steel wires to give strength. The cable is laid from the back of a ship which slowly moves forwards. If the water is very deep (e.g. 2 miles), the distance from the back of the ship to the place where the cable touches the bottom may be 15 miles or more (Fig. 26). This great length of cable is very heavy; it would break under its weight if it were not strengthened.

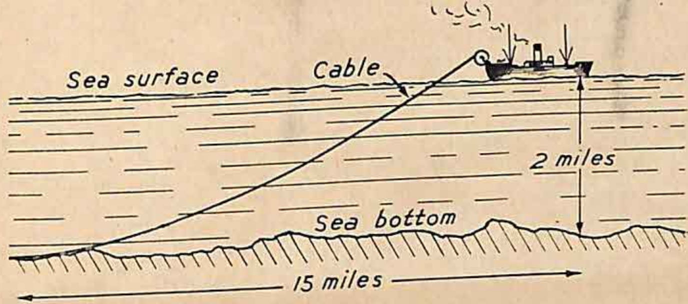
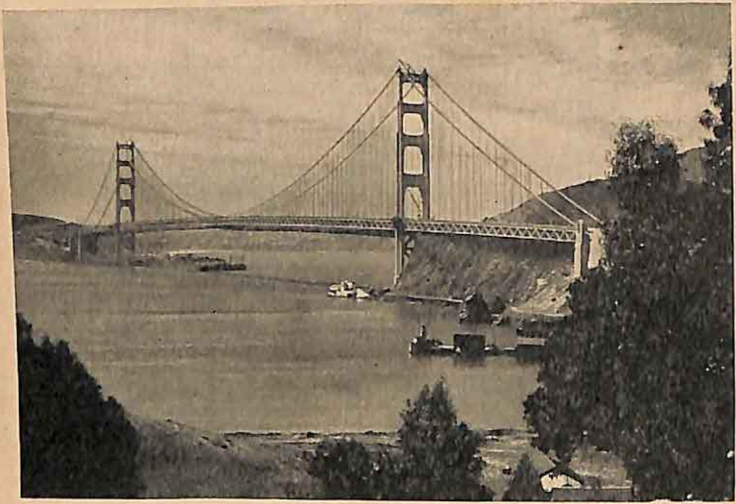


FIG. 26.

Passing to much smaller cables, most of us know the cables which are sometimes used for working the brakes of a bicycle or, more often, for working the "3-speed gear." This cable is called Bowden wire after the man who invented it. It consists of many thin wires twisted together inside a narrow metal tube. It is very strong and fairly flexible.

Another way of using the strength of metals and yet obtaining the property of flexibility is by making a chain. A chain consists of a number of links (rings) which fit loosely together. It is often said that the strength of a chain depends upon the strength of its weakest link, for, if a weak link breaks, the whole chain is broken. Chains are stronger than cables of the same size and weight, and are much used in shipping. The anchors of great ships, which are let down to the bottom of the sea to keep the



(*E. N. A.*)

Suspension bridges depend upon the strength and flexibility of chains. The picture shows the Golden Gate Bridge, San Francisco (U.S.A.). The centre " span " is over 4,000 feet long.

ship still, would need cables of such size that they would be too heavy for men to manage. Chains are easier to handle.

Although chains are chiefly used like ropes for pulling and lifting, we must not forget another of their uses. They can be used for carrying power from one place to another. You have a very good example of this on your bicycle. You supply the power by pushing on the pedals. By means of the chain, the power is carried to the back wheel. Chains used for such purposes are usually " roller " chains. Look at your bicycle chain. The links are joined together by little rollers (Fig. 27). When the wheel turns, the links always fall exactly in place on the " teeth."

There we must leave metals for a time. Although they

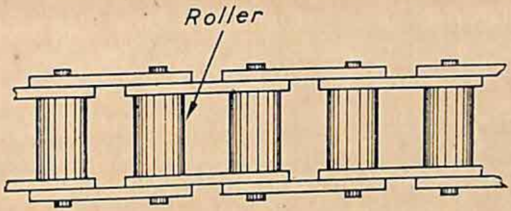
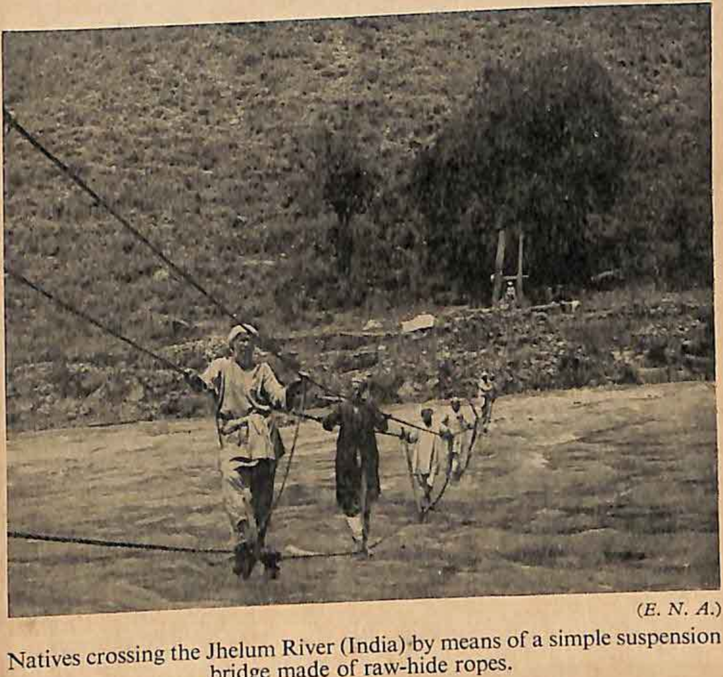


FIG. 27.

have the property of strength we can only obtain the property of flexibility by using them in special ways. Let us now turn to some other materials which have, perhaps, rather less strength but are very flexible. These



(E. N. A.)

Natives crossing the Jhelum River (India) by means of a simple suspension bridge made of raw-hide ropes.

are the materials like rope, string, cotton, and wool. All these materials are alike in one way. They are made up of fibres. You can often separate some of the fibres with a pin. These fibres, of course, are *very* much bigger than molecules, but, if they are examined in a special way with X-rays, it is found that each fibre contains thousands and thousands of much smaller fibres lying side by side. Each of these smaller fibres is really a giant molecule (p. 125). Fibrous materials, that is materials made of fibres, have the important properties of strength and flexibility.

Rope and string are usually made of hemp. There are several different kinds of hemp, made from different plants. The true hemp plant grows in countries which have a warm, damp growing-season. It first grew in central Asia, but is now grown in Russia, Poland, and parts of the United States. The plants have tall, hollow stems. After the plants have been cut and the leaves taken off, the stems are left to dry and then soaked in water so that the softer parts rot. The tougher fibres, which form part of the stem, can now be separated, cleaned, and combed. They are then spun (twisted) into string and rope. Manila hemp comes from a plant which grows in the Philippine Islands. It is lighter in colour than true hemp, and is very strong and little affected by water. Sisal hemp comes from the big, hard leaves of a plant which grows in large quantities in Mexico and Tanganyika. The tensile strength of a good rope is about 3 tons per square inch. Many metals, of course, are stronger than rope, but rope has the useful property of flexibility.

Another important fibre is obtained from the jute plant. This plant grows in the wet lands near the mouth of the Ganges River in Pakistan. It is sometimes used for making cheap string but it is not very strong. Its chief use is in the making of sacks for potatoes, grain, sugar, etc.

Flax was probably the first of the fibres to be used by Man. Like hemp and jute, it is obtained from the stems of a plant. The fibres are soft and very flexible but also very strong. They can be spun into a very strong thread and used for sewing shoes and making fishing-lines. Much flax thread is woven into a kind of cloth. Such cloth is called linen.

(From the Imperial Institute Collections, South Kensington)

Cutting jute. The plant grows 8–12 feet high on the wet land at the mouth of the Ganges River (Pakistan).

The fibre which is most widely spun and woven into cloth is cotton. Cotton fibres grow as white hairs on the seeds of the cotton plant. Nearly half the world's supply of cotton is grown in the southern parts of the United States. The fibres, which are usually about an inch long, are spun into a thread and then woven into cloth. Much of this is done in the great cotton factories in Lancashire (England). We depend upon the tensile strength of cotton when we use cotton thread for sewing our clothes together. Cotton is very strong. A single fibre of raw cotton can support a weight which is several million times its own weight. It cannot be used, however, for making rope because it is affected by moisture.

(E. N. A.)

Branch of the cotton plant showing the cotton " bolls."

You will have noticed that all the fibres which we have so far described come from plants. Other important fibres are obtained from animals. Wool is a fibrous material. We do not use it for making things of great tensile strength but, of course, it is much used for making cloth. Some animals are able to make very strong fibres. The spider, for example, makes threads from which it spins its web. A spider thread is surprisingly strong when you remember how thin it is. Perhaps the most interesting fibre made by an animal is that made by the silk-worm. This creature is not really a worm ; it is the caterpillar of a moth. When the caterpillar is fully grown, it finds a quiet place and pours out a jelly-like substance through two small holes in its head. The substance hardens to form threads of silk. The caterpillar winds the threads round and round itself and, if left alone, would make a case inside which it can turn into a moth. Most of the world's silk is produced in China and Japan. The threads are very long and need very little twisting to form a useful thread. The thread is usually woven into material for dresses and other clothes. These long silk fibres are so useful that Man has tried to make similar fibres from other materials. We shall read in Chapter XIII of the "artificial silk" which is now widely used in the place of the true silk.

Probably you have never tried to kill an elephant with a spear ! If you did try you would find that its hide (skin) is very strong and tough. Animals' skins have been used

(E. N. A.)

Silk-worms feeding on mulberry leaves.

(*E. N. A.*)

Inside a silk-worm shed of a Japanese farm.

by Man for countless ages whenever he needed a material which was strong, tough, and flexible. Leather is usually made from the skin of cattle or goats. We use it for many purposes. It is used for making bags, straps, seats (on bicycles and horses), and belts. Leather boots and shoes are often tied up with leather laces. No other material which is as cheap is so strong, flexible, and comfortable to the touch.

A good example of the use of both the strength and flexibility of leather is seen in the "pulley belt." Fig. 28 shows one pulley wheel A driving another pulley wheel B. They are joined by a leather belt. The leather must be strong to carry the pull in the upper part of the belt and flexible so that it can bend round the pulleys easily and quickly. Such pulleys and belts are much used in factories for driving machines. Chain belts, as in a bicycle, waste rather less power, because they cannot slip, but they are heavier, more costly, and often noisy. Pulley belts are sometimes made of other materials but the most common ones (and, often, the most useful ones) are made of leather.

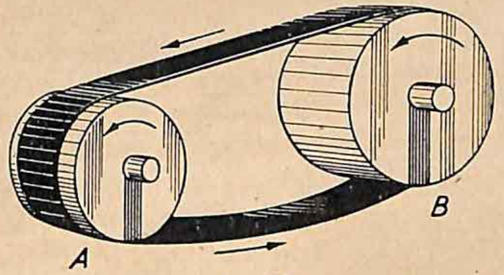


FIG. 28.

CHAPTER VIII

ELASTICITY

ALTHOUGH, in modern times, a soldier's chief weapon is a gun, the soldiers of 600 years ago carried quite different weapons. One of the most important of these weapons was the bow and arrow. It has been said that the English people won their great battles at that time because they were so good at making and using bows. We read of the bow quite early in the Bible. Some of the wildest tribes of Africa, America, and Asia still use the bow and they are very skilful with it. A bow is a piece of good, tough wood, shaped in a shallow curve, with a piece of cord (strong string) tied tightly from end to end. It is held near the middle and the arrow is held with its back end against the cord. The arrow is pulled back so that the bow is bent more sharply (Fig. 29) and then released (set free). It may travel forward several hundred yards.

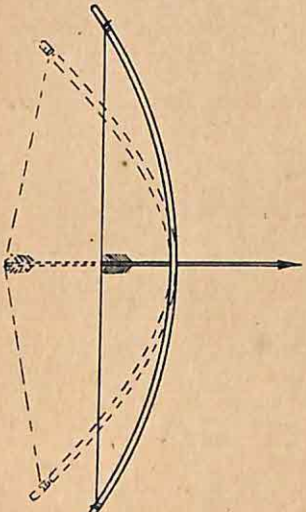


FIG. 29.

Why does the arrow fly forwards ? When the arrow is pulled back, the bow is bent more sharply ; the shape of the bow is changed. When the arrow and string are released, *the bow regains its first shape*. It springs back to its first shape with such force that the arrow is shot forwards.

A schoolboy often likes to make a "catapult." He chooses a Y-shaped piece of stick and ties a piece of elastic across the top. Sometimes he sews a piece of leather in the middle of the elastic. He holds a small stone in the middle of the elastic with one hand and the bottom of the stick with the other hand. He pulls the elastic back and then releases the stone. The stone flies forwards much further than he can throw it. From where has the power come ? The elastic is stretched when it is pulled back. When it is released it regains its first length with such force that the stone is sent forwards.

We have described two examples of a very important property. The bow is bent out of shape but it regains its shape when the force is taken away ; the elastic is stretched but it regains its true length when the force is taken away. We often meet this property. The wind bends the tree-tops and the stems of plants ; when the wind has passed they go back to their upright positions. You can press a small hollow in a football with your fingers ; when you stop pressing, the ball regains its shape. We can bend the metal blade of a saw but it becomes straight again when we release it. We make use of various kinds of springs. A spring stretches, or becomes shorter, or bends, when a force acts on it, but it regains its size or shape when the force is taken away.

This property of regaining size or shape is called "elasticity." We say that the material is "elastic." Notice that the material which we call Elastic is only one of the many materials which have this property of elasticity. Wood, as in a bow, is elastic; steel, as in a spring, is elastic. Soft materials like clay and cheese are not elastic. If you stretch a piece of clay it does not regain its shape.

Here is an experiment which you can try with a rubber ball. Cover a board with white chalk and bounce the ball on it. Notice the size and shape of the mark made on the ball. Can you draw the shape of the ball at the moment it is bouncing on the board? The underside of the ball becomes flat at the moment of bouncing. The ball regains its shape and so jumps up again.

About 300 years ago an English scientist named Robert Hooke studied the relation between the change of length of an elastic material and the size of the force which caused it. You can try a similar experiment yourself. You need a piece of thick elastic or a rubber cord. Fix one end to a support so that the cord hangs down and tie a round tin-lid on the bottom to form a small pan (Fig. 30). Fix a scale of inches and parts of inches at the side of the cord (you can use a ruler) and stick a pin through the cord so that its pointed end comes in front of the scale. Read the position of the pin on the scale.

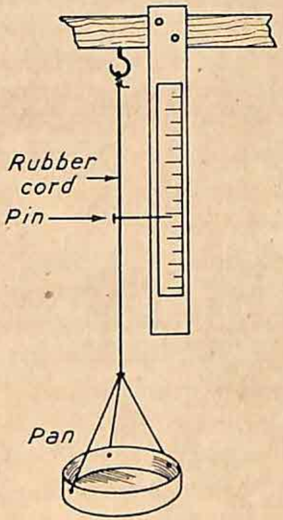


FIG. 30.

Now put a small weight,[1] such as $\frac{1}{4}$ lb, in the pan. The rubber stretches and the pin moves down. Read the new position of the pin. By taking the first measurement from the second you can find the *increase in length*, i.e. by how much the rubber has stretched. Add another $\frac{1}{4}$ lb weight, read the new position of the pin, and again find the *total* stretching (from the start) caused by the $\frac{1}{2}$ lb (i.e. $\frac{1}{4} + \frac{1}{4}$) weight. Continue in this way and so find the total stretching caused by $\frac{3}{4}$ lb and 1 lb weights. Can you discover a relation between the size of the weight and the amount of stretching it produces? You probably find that when you make a weight twice as big (e.g. from $\frac{1}{4}$ lb to $\frac{1}{2}$ lb), the amount of stretching is twice as much (e.g. a stretch of 2 inches instead of 1 inch). When the weight is made 3 times as big, the amount of stretching is 3 times as much, and so on. We say that the amount of stretching is "proportional to" to the size of the force (the weight); they change in the same way together. You can try a similar experiment with a thin metal spring. (Do not choose a very stiff spring or your weights will not be able to stretch it far.) Do you find the amount of stretching and the size of the force are again related in this way?

If, in these experiments, we use very big weights, we may stretch the rubber (or the spring) so much that it does not regain its length. The material is only elastic up to a certain limit. But if the forces are not too big the material can regain its length; it remains elastic. It is always found that, if the weights are not too big, the change in length is proportional to the force. We call this fact Hooke's law.

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[1] The sizes of the weights which you should use depend upon the thickness of the cord. If you use a cord made from a thin elastic "band" you can use pennies as weights.

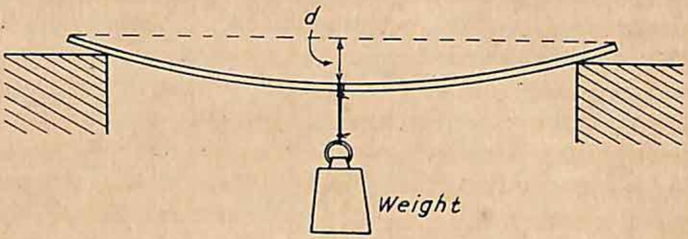
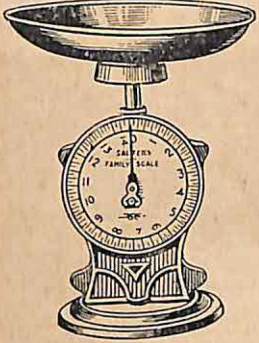


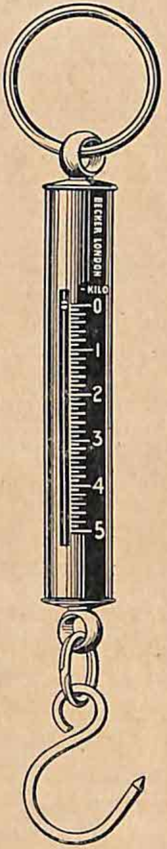
FIG. 31.

Hooke's law is true, not only for stretching, but for other changes of size or of shape. Fig. 31 shows how you can test the bending of a thin strip of wood. You can most easily measure the amount of bending by measuring the distance *d* through which the middle of the strip is pulled down. You will find that the distance *d* is proportional to the size of the weight.

When a metal bar is stretched, the atoms (or molecules) are pulled further apart. The forces between the atoms (the force of cohesion) try to hold them back. As soon as the force causing the stretching is taken away, the force of cohesion pulls the atoms back to their proper places. The bar regains its shape; it is elastic. Very big forces pull the atoms so far from their proper places that they take up new positions. They stay in these places when the force is taken away. The bar does not regain its shape. The atoms in poorly elastic materials like clay are pulled into new positions by very small forces. The material does not regain its shape even after very slight stretching.

Now let us go back to our experiment on the stretching of a rubber cord (Fig. 30). Suppose we paste a strip of clean paper over the scale and make a mark on it to show the position of the pin when there is no weight in the





pan. We can call this mark 0. Let us make marks to show the positions of the pin when there is $\frac{1}{4}$ lb, $\frac{1}{2}$ lb, $\frac{3}{4}$ lb, and 1 lb in the pan. How will these marks be spaced? The distances between them will be equal (Hooke's law). We can add further marks to show the position of the pin for each ounce up to 1 lb. We have now made an instrument which we can use for weighing things. Suppose we put a stone in the pan and the pin comes against the $\frac{1}{4}$ lb mark. We know that the stone weighs $\frac{1}{4}$ lb. We can make a better instrument by using a steel spring instead of the rubber cord. Our instrument now becomes a "spring balance." We can buy such instruments in shops. The spring is put inside a metal case and the marks made on the outside of the case (see the picture on the right). Such an instrument is very useful for quick weighing when accuracy is not needed. Another kind of spring balance is shown above. The thing which is to be weighed is put on the pan at the top and a "pointer" moves round a scale to show the weight.

The spring balance is but one example of the many uses which we make of springs. Most springs are made of steel, indeed it is hard to make a good spring of any other material. In some instruments (such as the simple spring balance which we have described) a spring is stretched but in many instruments a spring is compressed. Look at Fig. 32. The first drawing shows a spring with the turns of wire wide apart. The second drawing shows a weight W on the top of the spring. The spring is compressed; the turns of wire are closer together. Springs which are compressed are less likely to break than those which are stretched. Can you think of some uses of springs which are compressed? You often find them in beds and the seats of chairs. When you sit on the chair the springs are compressed. They enable the seat to change its shape to suit your body. When you get up the springs push the

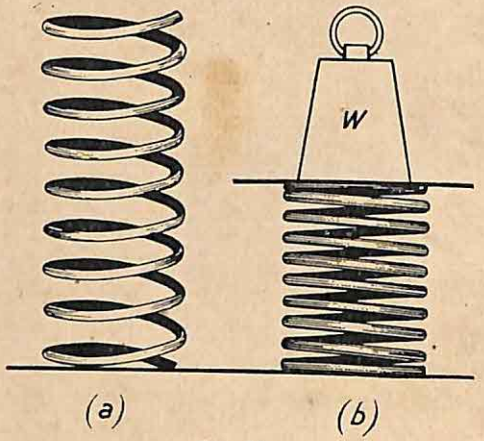


FIG. 32.

seat back to its proper shape. You may find compression springs under the seat of your bicycle. Fig. 33 is a simple drawing of a common kind of "buffer" on a railway

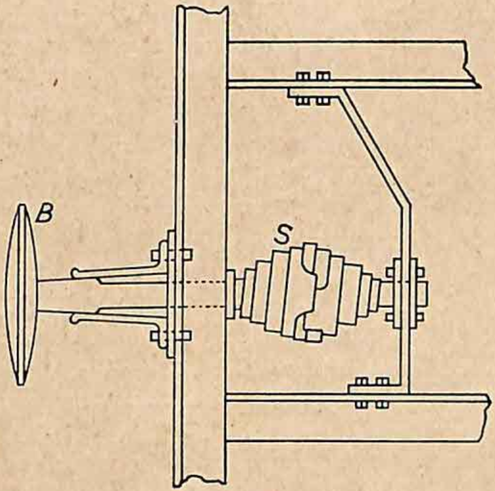


FIG. 33.

truck. When two moving trucks come together, the buffers meet and prevent a sharp, sudden knock. Behind the buffer B there is a special compression spring S. When the buffer is hit it moves inwards, compressing the spring, until the force of the spring stops it. Look round for more examples of compression springs. You will find a spring in your bicycle pump (to stop the handle from knocking against the top when you pull it up), there is one inside a petrol-lighter to force the "flint" against the wheel. No doubt you can find many more.

The springs on the wheels of cars, carts and many kinds of railway carriages, depend upon a different idea. A bar which is bent out of shape by a force regains its shape

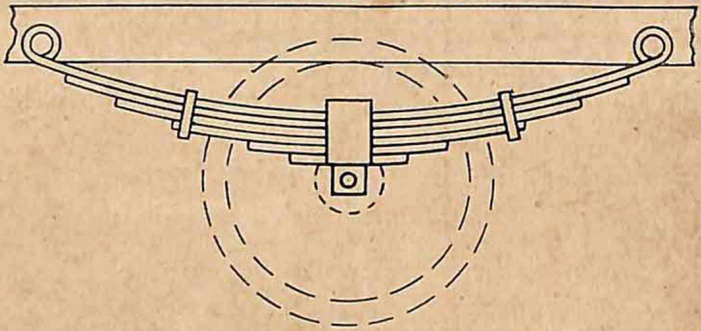
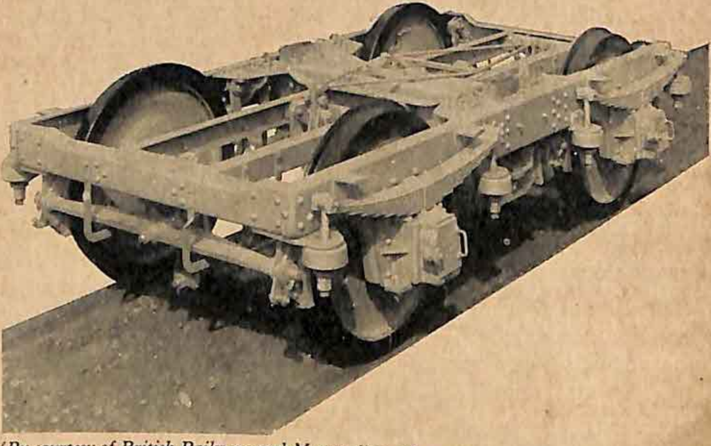


FIG. 34.

when the force is taken away. Fig. 34 is a simple drawing of a spring on a car. The spring consists of several strips of steel shaped something like a bow. Because it is made up of several thin strips it is usually called a "leaf spring." If, now, the wheel goes over a stone, so that it jumps



(By courtesy of British Railways and Metropolitan-Cammell Carriage and Wagon Co. Ltd.)

A "bogie" for a railway trailer. Notice the leaf-springs above the axles.

upwards, the spring bends, and the car does not jump. When people get in and out of the car, the spring bends up and down.

There are other springs which depend upon the bending of a strip of metal. You can usually find such springs, for example, in an ordinary door-lock. A clock spring really depends upon the same idea. The steel strip is made into the shape of a spiral. When the spring is "wound up" it is bent into a smaller, closer spiral. It gradually unwinds, regaining its first spiral shape, and, in doing so, turns the hands.

When a ball bounces both the rubber *and the air inside it* change shape (and quickly regain it). Air is very elastic. We can easily change the shape of some air but it easily regains its shape when the force is taken away. We can, for example, press a lot of air into a small space, as we do when we pump up a bicycle tyre, but the air quickly regains its size if it is set free, as it does when we make a hole in the tyre! An air-filled tyre, like that on a bicycle or car, is an important use of the elasticity of the air. Cart wheels are often made of hard wood with, perhaps, iron rims (edges). They sink into soft ground and jump when they hit stones on the road. Solid rubber tyres are better. It was the Scotsman John Dunlop who thought of filling a rubber tube with air and fixing it to the edge of the wheel. The air-filled tyre flattens slightly on the ground and bends over a stone. Now we ride very smoothly in cars. There are springs in the seats, leaf-springs on the axles, and air-filled tyres on the wheels. Our comfort depends very much upon the wonderful property of elasticity.

We must not leave this chapter on elasticity without describing another very important use of this property. We depend upon elasticity in order to hear; without this property there could be no sounds. Stretch a rubber band between a finger and thumb (Fig. 35a) and pluck one side with a finger of the other hand. The rubber makes a short sound. Look at the rubber immediately after you have plucked it. It is moving very quickly backwards and forwards (see drawing). When you pluck the rubber you pull it to one side and slightly stretch it. It regains its shape but moves so quickly that it stretches out again on the other side. It moves quickly backwards and forwards for several times before coming to rest. We say that the rubber vibrates. And when it vibrates it makes a sound. Here is another experiment. Hold an ordinary dinner-fork by the handle, tap the points on a table, and quickly hold the fork with its handle standing on the table. The fork makes a ringing sound. Now tap the points again on the table and quickly hold the fork so that the points touch against your teeth. You can feel that the points are vibrating. When you tap the points you bend them slightly to one side. Then they move quickly from side to side several times before they come to rest in the middle. It is this vibration which causes the sound. The skin of a drum vibrates in and out when it is hit and so makes the sound. Things could not vibrate like this if the materials of which they are made were not elastic.

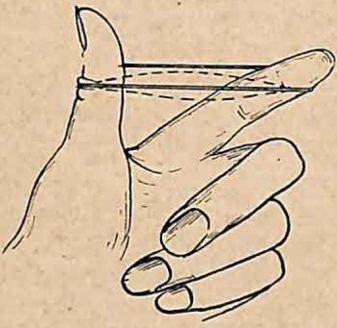


FIG. 35a.

Let us return to the vibrating fork. When the points move outwards they compress a little of the air in front of them. When they move inwards they leave a little space which contains less air than usual. Travelling away from the fork, then, there are little pulses of compressed air (*c*) with spaces of low-pressure air (*l*) between them (Fig. 35b). When such a row of pulses strikes the ear we "hear" the sound. These pulses would not be formed, and would not travel, if the air were not elastic.

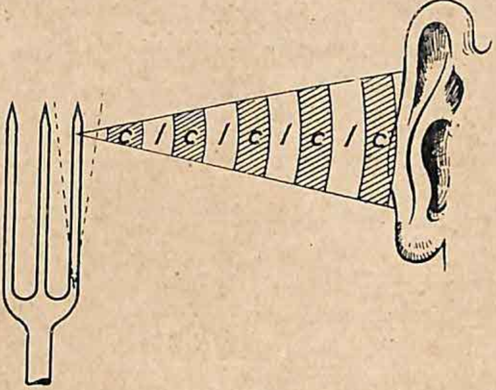


FIG. 35b.

Elasticity, we see, is a very useful property. It enables us to hear, it enables us to make springs to lessen the force of knocks (as in a car) or to give us power (as in a clock). We depend upon it for our ball games. It enables plant stems, such as corn, sugar cane, and jute, to bend over before the wind and not be broken. The world would be a very uncomfortable place if solid things could not slightly change their shapes—and a very strange place if solids could not regain their shapes!

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CHAPTER IX

SOME HARD MATERIALS AND THEIR USES

AFTER we have cut a piece of wood with a saw we sometimes make it smooth by rubbing it with sandpaper. There are hundreds of little grains of sand on the paper and these wear away the rough parts of the wood and so make the surface smooth. We sharpen knives and other cutting tools by rubbing them on a grindstone. The hard stone wears the metal and gives it a sharp edge. Have you tried to cut a piece of glass? You cannot cut glass with a knife; the glass is too hard. But you can make a deep scratch with a "glass-cutter" and then break it. There is usually a small diamond on the end of a glass-cutter. This is harder than the glass and so can scratch it.

These are some examples of the uses of hard materials. The sand grains are hard, the grindstone is hard, the diamond is hard. What exactly do we mean by hardness? We use the word to describe two similar but slightly different properties. We say that a material is hard if we cannot scratch it easily. Steel is hard, soap is not. You can scratch soap with your finger-nail but you cannot scratch steel in this way. Then we also say that a material is hard if we cannot easily press a hollow in it. We cannot press a hollow in a steel bar with our fingers; steel is hard. But we can easily press a hollow in some butter, or some putty with our fingers; these materials are not hard. A material is "hard" if it is difficult [illegible] to scratch it or to make a hollow or a hole in it.

Suppose you were asked to arrange these following materials in order of hardness: marble, copper, soda, glass, paraffin wax, mild steel (a nail), tool steel (e.g. a file). How would you do it? You could choose one material, for example the piece of copper, and find out which of the other materials it can scratch. The copper is harder than the materials which it can scratch but not so hard as the materials which it cannot scratch. By testing all the materials in this way, you could arrange them in order of hardness.

This test tells you which of two materials is harder but it does not *measure* the hardness by giving it a number. A simple way of giving a number to show hardness is to arrange ten materials in order and then number them from one to ten. This was done by a man named Mohr. He chose ten minerals (pure rock materials). He found that a diamond could scratch all the other materials in his list and it was therefore the hardest. He gave it the number 10. The next hardest material was corundum. This is the material of which the jewels ruby and sapphire are made. Corundum cannot scratch a diamond but can scratch all the others in the list. Mohr gave it the number 9. Continuing in this way, he numbered all the ten minerals of his list. The full list, called Mohr's scale of hardness, is as follows:

10. Diamond.
9. Corundum (ruby, sapphire).
8. Topaz (a jewel; white topaz is often found in the tin-mines of Nigeria).
7. Quartz (rock crystal of sand).
6. Felspar (the big white crystals seen in granite).
5. Apatite (a rather uncommon mineral; window glass has about the same hardness).
4. Fluorspar (blue or green mineral, sometimes used for making ornamental pots, etc.).

3. Calcite (a crystalline form of limestone).
2. Gypsum (mineral which looks something like marble but is much softer).
1. Talc (white or greenish mineral, used, like chalk, by tailors for marking on cloth).

We can use this scale as follows. Suppose we want to know the hardness of a piece of steel. We find that the steel can scratch felspar but is itself scratched by quartz. So its hardness is between 6 and 7. We can call it 6½. You see that we are able, in this way, to give the hardness of the steel a number. You may like to remember that things of hardness 1 and 2 can be scratched with a finger-nail, things of hardness 3, 4, 5, 6 with an ordinary pocket knife, but things of hardness 7–10 cannot be scratched with a knife.

We have said that the hardness of a material does not only mean the difficulty of scratching it, but also the difficulty of pressing a hole or a hollow in it. So there is also another way of measuring hardness. We can press a certain tool into the material, using a force of a certain strength, and find out the size of the hole which is made. In one kind of machine, called the Brinell hardness tester, a hard steel ball (about $\frac{2}{5}$ inch across) is pressed into the material. If the material is fairly soft a big hollow is made; if the material is hard only a small hollow is made. The hardness is worked out by dividing the force which is used by the area of the hollow which is made.

These two ways of measuring hardness give different numbers. Thus a certain kind of steel may have a hardness of 6½ (Mohr's scale) and 117 (Brinell). So in stating the hardness of a material we must say on which scale the measurement was made. Now let us look at some hard materials and the uses which we make of them.

A diamond is the hardest material known. Its atoms are close together and very strongly joined. Each atom is strongly joined to four other atoms (Fig. 9, p. 32). Clear, pure diamonds, of course, are used as jewels. They are very costly and an engineer could not afford to use them for other purposes. But there are also poor, dark-coloured diamonds which are of no use for jewels. These are of great use for other purposes.

A tool for cutting a hole in a hard material is called a "drill." (You probably know the kind of drill which is used for making holes in wood.) Drills, of a different kind, are used in mines for making holes in rocks. A tube-shaped drill is turned round quickly in the face of the rock and it slowly cuts out a round stick of rock. A steel drill soon loses its sharp edge because many rocks contain sand and quartz, and these are harder than the steel. So a number of strong, pointed diamonds are set in the cutting edge (Fig. 36). The diamonds can cut into the rock much better than the steel.

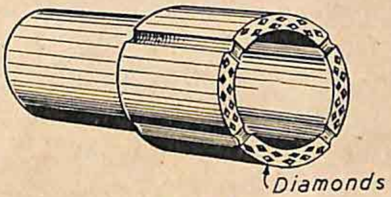
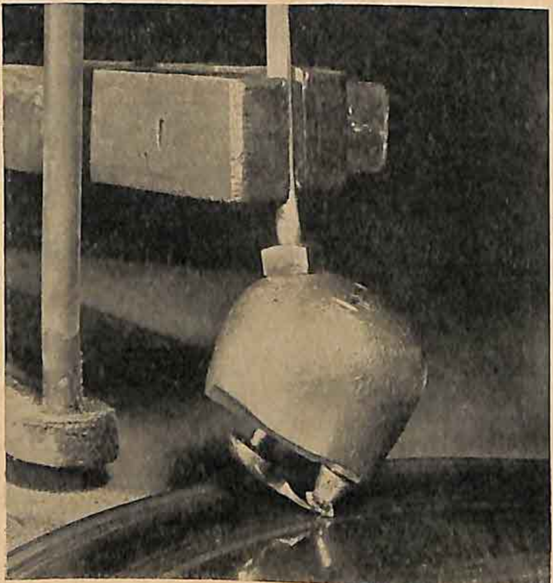


FIG. 36.

Diamond "dust" is used for polishing other diamonds in the making of jewels. It can also be used on the edges of saws for cutting rocks but more often a cheaper hard material is used. It would take you a long time to guess the most important use of diamonds. Very fine wires, like those in electric lamps and the "hair-spring" of a watch, could not be made without them. In the making of a wire (p. 97), a rod of metal is pulled through a hole a little smaller than itself. It is then pulled through a smaller hole, and so on, until a wire of the right thickness is made. The hole must be made in a very hard material because the sides of the hole become worn with the miles of wire which pass through. The thinnest wires are made by pulling a thicker wire through a hole in a diamond. As you can well imagine, the drilling of the hole through a diamond is a difficult process. The drill consists of a steel needle. On its end there is some olive oil containing fine diamond dust. Holes as small as 35 hundred-thousandths (0·00035) of an inch have been made.

The next hardest material on Mohr's list is corundum.



Polishing the faces of a diamond to make a jewel. The diamond is held against a flat, quickly turning wheel which is coated with olive oil and diamond dust. Each face must be polished separately at the proper angle.

This is a crystalline form of aluminium oxide. If it contains a small amount of impurity which gives it a blue colour we call it a sapphire and if an impurity gives it a red colour we call it a ruby. Both sapphires and rubies form nice jewels. Small jewels are used in a watch. Sometimes you see an advertisement of a watch "with fifteen jewels." The wheels of a watch go round for many years and are not often oiled. The ends of the axles must be supported in holes made in a very hard material so that they do not become loose or get out of place. So the axles are supported in fine holes drilled in jewels (often small rubies or sapphires). In a good watch there are also jewels at the ends of the axles (Fig. 37).

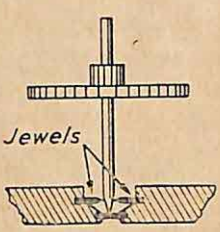


FIG. 37.

In some parts of the world a rock is found which consists of a mixture of corundum and a kind of iron ore. This black material is called "emery." Emery is much used for grinding and polishing. It is made into small grinding wheels (for grinding chisels and other cutting tools) or stuck on paper or cloth and used for polishing metals. Needles are sharpened by emery. Thousands of needles are laid on a canvas sheet, covered with emery and soft soap, and the canvas rolled up. This is then turned round and round between heavy rollers for many hours. In this way the needles are ground by the emery so that they become bright and the points are properly shaped.

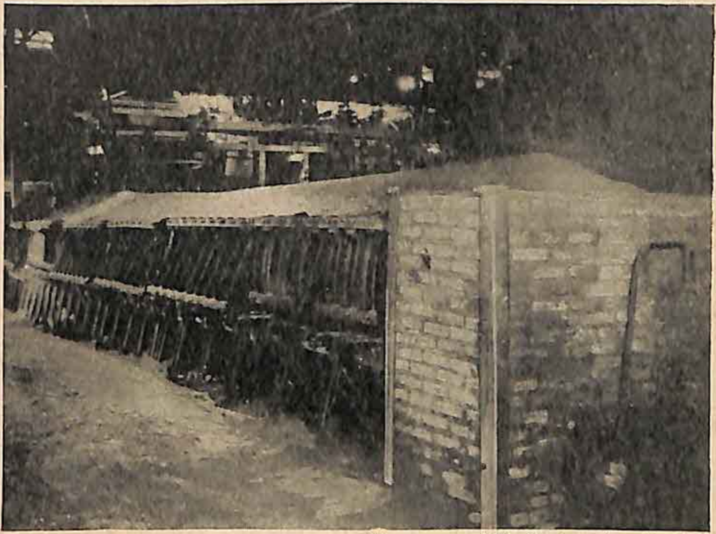
Many rocks consist of masses of particles firmly stuck together. Sandstone, for example, consists of sand grains (quartz); granite consists of three different minerals. The hardness of a rock depends not only on the hardness of the grains but also on the way they are stuck together.

Some kinds of sandstone are fairly soft although they are made of hard sand grains. When you scratch the rock you break off some of the grains but do not scratch the grains themselves.

One of the hardest rocks is granite. It is too hard for many building purposes but is used for building lighthouses, harbours, and bridges. Sometimes lumps of granite are rolled into the ground in road-making. Such roads can withstand the wear caused by cars, carts, etc., for a long time. Many fine buildings are made of the harder kinds of sandstone and limestone. Look at any big stone buildings in the town where you live. Can you tell of what kinds of stone they are made?

Grindstones for sharpening knives, axes, etc. are often made of hard sandstone. The hard grains of sand wear and polish the edge of the tool and make it sharp. As you know, Sheffield (England) is noted for the making of knives and cutting tools. The grindstones are made of a rock called " Millstone Grit." This rock is dug up near Sheffield and is one of the reasons why this industry is carried on there.

Sand grains (quartz) have a hardness of 7 on Mohr's scale. They are harder than glass and many rocks, and slightly harder than most metals. Sand has been used for ages by stone-workers to help to cut and polish their stone. Loose sand is often used with a saw, or even with a piece of iron, for cutting stone into suitable shapes and sizes for building. The wood-worker uses sand-paper for making his wood smooth. Do you know the material which we call " ground glass "? The glass has a slightly rough surface so that, although it lets light through, you cannot see through it. It is made by blowing sand against the glass with great force. The sand grains make millions of little cuts in the surface. A similar process is used in steel works for cleaning and polishing metal.



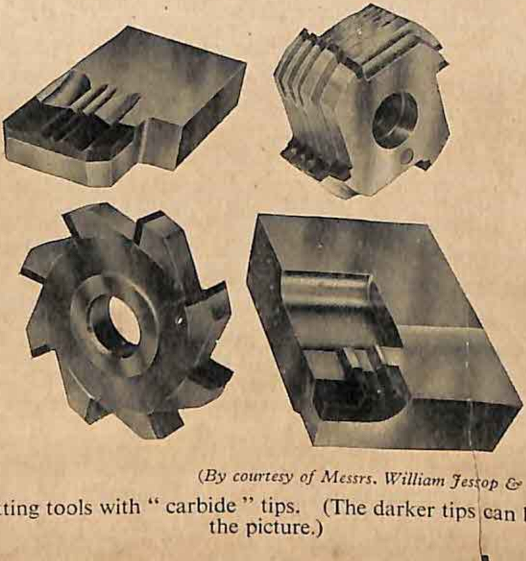
(*By courtesy of The Carborundum Co. Ltd.*)

A Carborundum furnace.

You will have noticed that all the hard materials which we have described so far are found naturally, and that the hardest ones are jewels. It is not surprising that men have tried to *make* hard materials from substances which are cheaper. The best-known artificial hard material is "carborundum." (Do not mistake this name for corundum.) Carborundum is made by strongly heating a mixture of carbon and sand. It has a hardness of over 9 on Mohr's scale and so is harder even than corundum or emery.

The main use of Carborundum is in the making of grinding wheels and grindstones. The hardest wheels are made by mixing the Carborundum with a suitable kind of clay and " firing " them (heating strongly in a furnace) as in the making of non-porous china. Other kinds of wheels are made by setting the Carborundum in a Plastic (p. 132) or in rubber. Although the most obvious use of Carborundum is in the making of grinding wheels, there are many other uses. It is used for making various kinds of drills, e.g. those for making holes in glass and, by a dentist, for making a hole in a tooth. Because of its cheapness and its hardness, Carborundum is now largely used in the place of emery.

Another hard material, which has been used more and more in recent years, is called tungsten carbide. It is a compound of carbon and tungsten (the metal used for the wire in an electric lamp). It is nearly as hard as Carborundum but is very brittle (easily broken) and so is of little



(By courtesy of Messrs. William Jessop & Sons, Ltd.)

Some cutting tools with " carbide " tips. (The darker tips can be seen in the picture.)

use by itself. This difficulty has been overcome by setting the small particles of the tungsten carbide in the metal cobalt. The material so made looks like a metal and is very suitable for making certain kinds of cutting tools. You may wonder how such hard tools can be sharpened. The grinding is first done with a Carborundum wheel and then with a wheel with diamond dust set in its edge.

Metals vary very much in hardness. Lead is a soft metal, so is pure gold. Aluminium and copper are fairly hard. The hardness of steel depends upon the amount of carbon it contains and the way it has been heated and cooled. Steel which contains up to ¼ per cent. carbon is harder and stronger than pure iron. We usually call it mild steel. It is used, for example, for chains, tins, ships, and bridges. A steel with 1 per cent. carbon is still harder and stronger. With greater amounts of carbon (e.g. up to 1½ per cent.) the hardness increases further but the steel is not so strong. Such " high carbon " steels are used for making tools (like files) and doctor's knives and scissors. Steel cannot be made both hard and tough. Thus razor blades which must be hard so that they keep a sharp edge are very brittle. Pocket knives, which must withstand more knocks, are not made so hard. They are stronger but cannot keep so sharp an edge.

Some steel alloys (which contain small amounts of other metals as well as carbon) are very hard and tough. One of these alloys is called manganese steel. It contains up to 13 per cent. of the rather uncommon metal manganese. It is used for making rock-breaking machinery and railway line crossings. Other hard steels contain nickel and chromium.

CHAPTER X

THE SHAPING OF SOFT MATERIALS

WE can take a lump of butter and spread it with a knife so that it forms a thin layer. The butter is soft. We can easily change its shape and it keeps the new shape which we give to it. We can change the shape of a ball of soft, damp clay by pressing it. We say that such materials are "plastic."[1] A plastic material, unlike a liquid, can keep its shape, but, unlike most solids, it is not firm.

You can probably think of examples of plastic materials which we use in the home. A woman who is cooking makes some "dough" from flour and water. She can roll the dough into a flat layer or press it into a baking-tin. The dough is plastic. After it has been baked in the oven it becomes firmer ; it is no longer plastic. A man who is fixing a new window in a window-frame uses a material called "putty." It is made from lime and linseed oil. He can press it into the cracks between the glass and the frame because it is plastic. Later the putty hardens and holds the glass firmly in its place. Children sometimes play with a soft, clay-like material called Plasticine. They can easily shape it into animals, houses, etc. The makers of the material gave it the name Plasticine because it is plastic.

A plastic material is most useful if, after it has been shaped, it can be made hard and firm. We notice that when a dough loaf is baked it becomes firm ; putty becomes firm when it is left for some hours in the air. Wet clay becomes hard when it dries but it becomes plastic again when it is mixed with a little water. If it is heated strongly it becomes very hard and firm and cannot be made plastic again. Certain chemical changes take place in the clay so that it really becomes a different material.

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[1] In recent years the name Plastic has also been given to certain other well-known materials. We shall read about these in Chapter XIII and learn why they are given this name.

(*E. N. A.*)

A corner of a potters' village, India.

Cups, saucers, pots, bricks, earthenware pipes and tiles are all made from plastic clay. Have you seen a travelling potter with his wheel ? He sets his flat wheel spinning and throws a lump of plastic clay in the middle. Then, with great skill, he shapes the clay into a pot. Many fine cups and saucers are made in North Staffordshire (England). There the potters work in a similar way but, of course, have much more machinery to help them. It is the round things which are made on a wheel. Handles of cups, for example, must be made separately and stuck on afterwards. When the vessels have been shaped they are baked in a hot oven. We sometimes say that they are "fired." This baking makes them hard and firm.

The nature of the finished article depends upon the kind of clay which is used, the kinds of other materials mixed with it, and the nature of the "firing." Very fine pottery, fired at a high temperature, is called porcelain. China, of which good quality cups, etc., are made, is a similar material. Both these materials are non-porous. Bricks, earthenware pipes, etc., are made from less pure forms of clay and are fired less carefully. Unless they are specially treated they are porous.

Most metals, as we have read, are strong, hard, and firm. Some, such as steel, are very elastic. But some metals are rather soft and, even when cold, are slightly plastic. Lead is such a metal. You can bend a lead pipe with your fingers; a piece of lead can be hammered into a thin sheet. Lead sheets, made by rolling, are used for roofs and containers for acids. Gold is another metal which can be hammered into thin sheets. This property was discovered thousands of years ago. Gold leaf, as the thin sheets are called, was used by the ancient Egyptians for decorating their temples. Gold "beating" is very skilled work and only a gold-beater knows how to make very thin sheets. The gold is put between two pieces of a kind of skin and hammered on a marble table. Gold leaf can be made so thin that 240,000 sheets are needed, piled on the top of each other, to make a thickness of one inch. The leaf is used for decorating picture frames and outdoor metal work. The cross and ball on the top of St. Paul's Cathedral (London) are covered with thin gold leaf.

When we were reading about the tensile tests of metals we learned that a small force causes only a little stretching and the bar remains elastic. Big forces, however, cause much more stretching and the bar does not regain its length. We have passed the elastic limit (p. 75). We can say that the bar becomes plastic when stretched by big forces. The scientist usually says that the bar becomes "ductile." (The word "ductile" means "able to be drawn out"; it comes from a Latin word meaning "to lead.") A piece of damp clay is always plastic but a metal bar is ductile only when big forces are used.

One of the most interesting uses of this property is the making of metal wire. The metal is made into a rod about $\frac{1}{4}$ inch thick. One end is pointed and pushed through a small hole made in a block of very hard material (e.g. tungsten carbide). The thin end is held firmly in a tool and pulled. As the rod is pulled through the hole it becomes thinner (Fig. 38 *a*). The thin end is

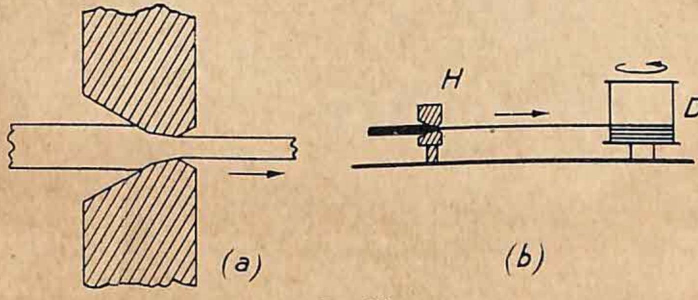
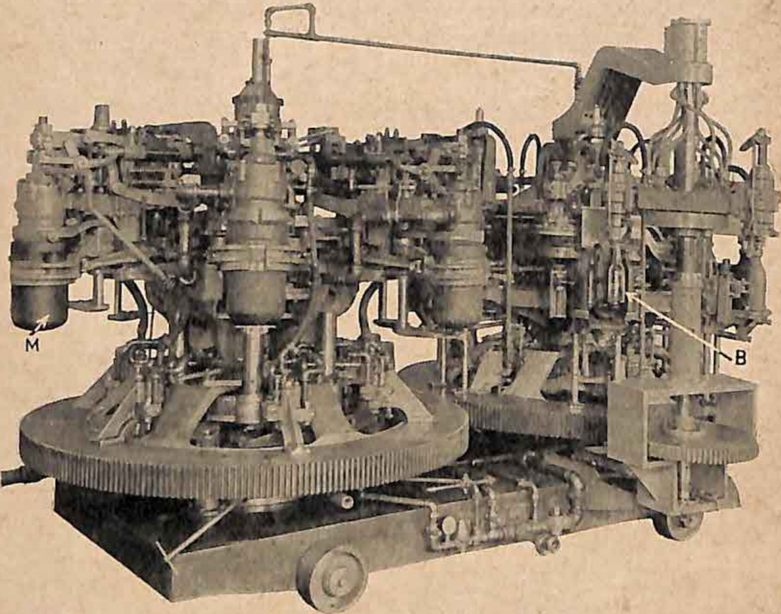


FIG. 38.

then fixed to a roller (like a drum) which turns round and pulls the rest of the rod through the hole. The wire is wound on the roller. This is shown in Fig. 38 *b*. D is the drum and H the hole. When all the metal has passed through the hole it is 10–40 times its first length. It is usually then passed, in a similar way, through a smaller hole, and so on, until the wire is of the right thickness.

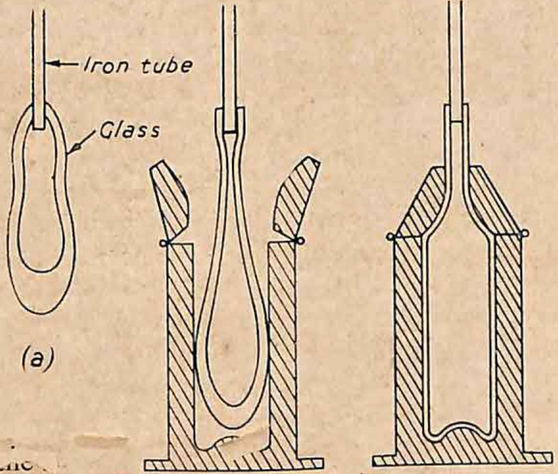
Some materials become plastic when they are heated. Ordinary wax, for example, softens when it is warmed (and later melts). A better example is the sealing wax which



(By courtesy of Messrs. O'Neill European Machine Co. of Montreal)

Bottle-making machine. Melted glass is sucked up into a mould M. The bottle is shaped inside the mould by compressed air. Later the mould opens and the finished bottle B is taken out.

we sometimes use for fastening up important letters and parcels. This material is a brittle solid when it is cold. When we warm it, it becomes soft so that we can press it into various shapes. Glass behaves in a similar way. If you heat a piece of glass it becomes softer and softer and you cannot say exactly when it changes from a solid to a liquid. It is this plastic property of heated glass which enables us to shape it into bottles, ornaments, and flat sheets. Some of the finest glass things are made by hand. A glass " blower " takes a lump of almost melted glass, at the right temperature, on the end of a hollow iron rod, and then blows. In this way he makes a round, hollow " bulb." While it is still hot and soft he can push it into the shape he wants with simple tools. Fig. 39 shows how a cheap bottle is made. Notice that the correct shape is obtained by blowing the bottle inside



(b) Mould open (C) Mould closed

FIG. 39.

[illegible]
two pieces

[1]

a " mould." Most bottles are made by machinery but the same idea is used. Much flat sheet-glass is made by rolling.

Most metals become soft and plastic when they are made very hot. They can then be shaped. A blacksmith makes a horse-shoe by hammering a piece of hot iron.[1] Hoes, spades, and ploughs can be shaped in a similar way. When Man began to make big things of metal, such as machines, trains, and ships, he needed hammers which would be more powerful than those he used with his hands. The drop-hammer consists of a heavy steel block which is lifted up several feet by a machine and then allowed to drop under its own weight on to the metal which is being shaped. In a steam-hammer the metal block is pushed down by the power of steam. A third kind of machine for shaping hot metal is the hydraulic press. The hammer-head is pressed down by water-power with a force which may be as great as 10,000 tons. The metal sides of motor-cars are usually made of steel which has been pressed.

There is another, rather different way of shaping hot metals. Paste for cleaning our teeth is usually sold in a thin metal tube. When we take off the cap and press the tube, the paste comes out in a long narrow strip. We form this long shape by pressing the paste through the narrow opening. Hot metals can be shaped in a similar way. Suppose a small block of copper is to be made into a round rod. It is heated to a bright red colour (750° C.) and then put into a press like that shown in Fig. 40 *a*. It is pressed down by the block R with great force (about 30 tons per square inch) and pushed out of the hole at the bottom. It comes out as a long thin rod. By using holes of different shapes, various kinds of rods and strips can be made. Fig. 40 *b* shows how a tube can be made. In the middle of the press there is a round stick S. This almost closes the hole at the bottom, leaving only a small

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[1] Ordinary " cast " iron is brittle and cannot be shaped in this way. A pure form of iron, called " wrought " iron, must be used.

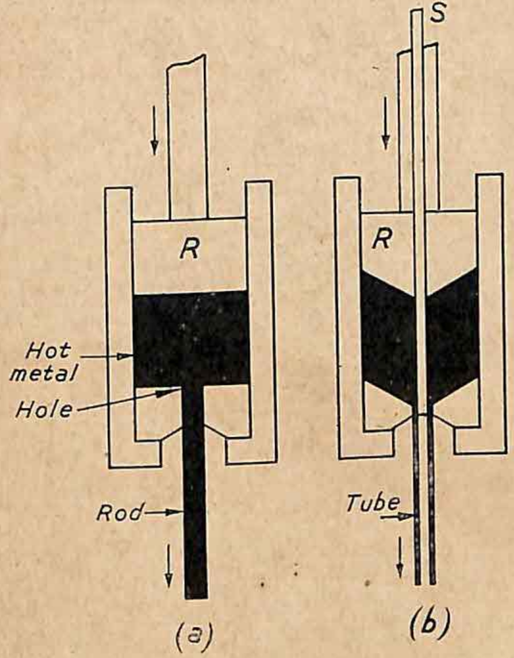
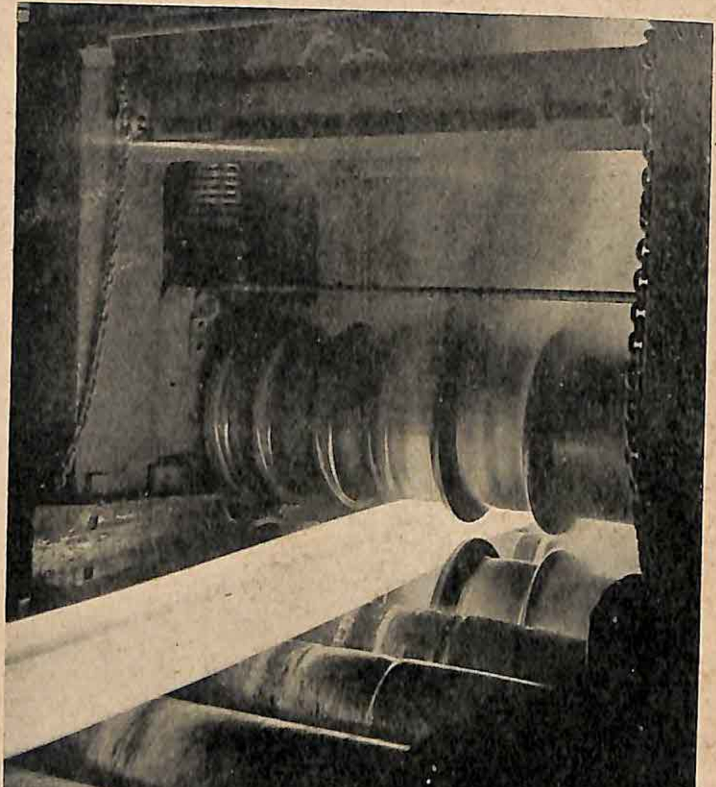


FIG. 40.

space round its sides. When the hot metal is pressed down, it comes out as a long tube. This way of shaping metals is much used for making rods, strips, tubes, etc., of [illegible] [illegible], copper, and lead.

two pieces [illegible]n the chapter we read how gold sheets are made [illegible]ring. Metal sheets can also be made by passing



(By courtesy of British Iron and Steel Federation)

A bar of white-hot steel passing through a rolling mill.

a metal bar between two powerful rollers. Fig. 41 shows the idea. The two heavy rollers are turned in opposite directions by machinery. The distance between them is less than the thickness of the bar. The bar is drawn along by the rollers and pressed into a thinner sheet. Metals

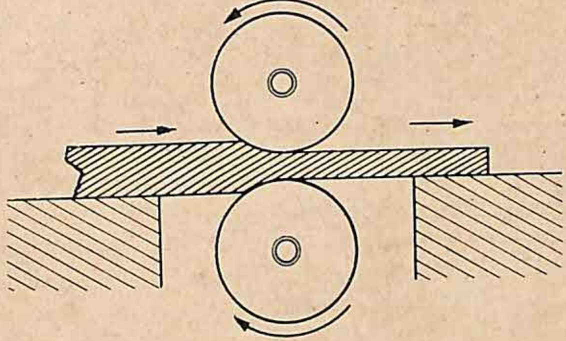


FIG. 41.

can be rolled when they are hot and plastic and also when they are cold. "Hot-rolling" is used for the first rough shaping of a piece of metal, but the shaping is sometimes completed by "cold-rolling." If the rollers are smooth and even, the bar, after rolling, becomes a strip or a sheet. But if the rollers have some definite shape, e.g. grooves in certain positions, the rolled bar is given a definite shape. The **I**-shaped railway lines are made by rolling steel bars. A hot bar is passed through several rollers which gradually make it longer and thinner. Then it passes through a second set of rollers which give it the **I** shape.

[illegible]
two pieces

CHAPTER XI

THE SURFACE TENSION OF LIQUIDS

MOST of our chapters have been about the various properties of solids. In this chapter and the next one we shall consider some properties of liquids. We have already learned the chief differences between solids and liquids. A solid is firm ; it is able to keep its shape. A liquid has not a definite shape. It must be kept in a container and it takes the shape of that part of the container which it fills. A liquid can flow ; we can pour it from one container to another.

We have been able to explain these differences between a solid and a liquid by thinking of the forces of cohesion which hold the molecules (or atoms) together. The molecules in a solid are close together, often in a regular pattern, and the forces which hold them are strong. The molecules cannot move about ; they are firmly held in their places. The forces of cohesion between the molecules of a liquid are weaker. The molecules can move about although they cannot move right away from each other. The liquid can flow because the molecules can easily move into new positions.

Some of the properties of a liquid are so well known that we need not spend much time in describing them. We often make use of the property of flowing. We pour liquids from one container into another, we make water flow along pipes, we pour drops of oil on the axles of moving machinery. We see water flowing naturally in the rivers and streams. We can use the pov wn along moving water to turn a water-wheel. Some l Metals more easily than others. Water and petrol flow easily but thick oil and treacle do not flow easily.

If we put some water in a bucket, it takes the shape of the part of the bucket which it fills. The bottom and sides of the water are shaped like the bottom and sides of the bucket. But the top surface of the water, where it meets the air, is flat and horizontal (level). The top surface of water in a still pool is flat and horizontal. Although the top surface of a still liquid is usually flat, we must not think that it is always so. Spill some water on a greasy table. It forms round drops. Look carefully at the surface of some water in a bottle. Is it quite flat where it touches the side of the bottle? A soap bubble has a round surface; no one has seen a square bubble with flat sides! Some of the most interesting and most important properties of a liquid concern its surface. It is these properties which we shall study in this chapter.

Let us start with a soap bubble. Every child, at some time or other, has blown soap bubbles on a pipe and watched them float away until they burst. Why are they round? Before the bubble breaks away from the pipe it is not shaped like a ball but as soon as it is free it becomes completely round. We can slightly change its shape by blowing on it as it floats by but it regains its shape. The bubble is much like a hollow rubber ball. The rubber of a ball is stretched by the pressure of the air inside it; it is "in tension." It tries to contract and make the ball smaller. We may wonder if the film of a soap bubble is in tension. Let us try some experiments.

You can make some soap solution by adding warm water to some small pieces of soap [1] and stirring well. Fig. 42 shows the first experiment which you can try. You need two pieces of wire each about 2½ inches long. Join them, as shown, by two pieces of cotton each about 3 inches long. Dip the apparatus right under some soap solution and lift it out again slowly. With care you can get a soap film between the wires. You see that the pieces of cotton do not hang straight. The soap film, not the cotton, supports the weight of the bottom wire. The film is in tension; it pulls the bottom wire upwards, the pieces of cotton inwards, and even tries to pull the top wire downwards.

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[1] Yellow soap is better than toilet (face) soap.

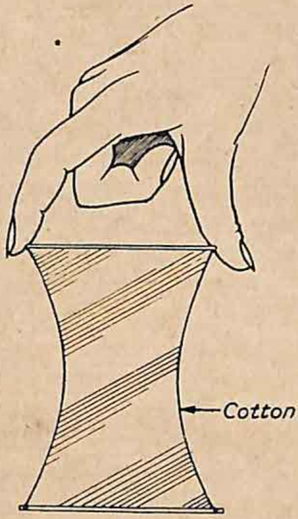

FIG. 42.

Now make some wire circles, about $1\frac{1}{2}$ inches across, with handles (Fig. 43). Tie a piece of cotton loosely across one of them, dip it into soap solution, and form a film right across the circle (*a*). Touch the film on one side of the cotton with a piece of blotting-paper (or, better, with a hot wire). That part

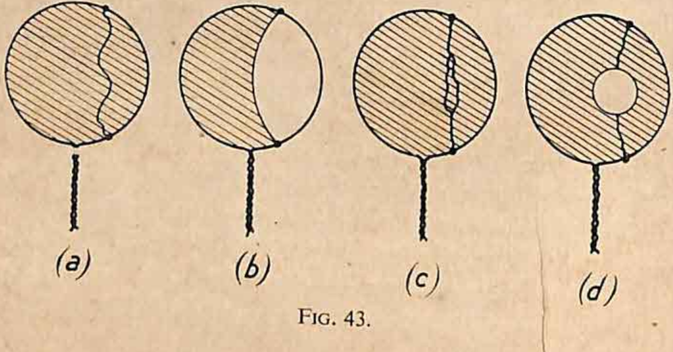

FIG. 43.

of the film breaks. The other part pulls the cotton into a smooth curve (*b*). The film is pulling inwards and trying to become as small as possible. Try the experiment again but this time make a loop in the cotton (*c*). Break the film inside the loop. (This needs a little practice !) The rest of the film pulls out the loop into the shape of a circle (*d*).

A soap film is like a " sandwich." There is a soapy skin at the surface on each side with water (chiefly) in the middle. These skins are in tension. They pull inwards and try to make the surface of the film as small as possible. We may think that soap solution is rather a special kind of liquid (as, in some ways, it is). Is there any kind of skin on the surface of an ordinary liquid such as pure water ? Let us try some more experiments.

If you throw a steel sewing needle into some water it sinks to the bottom. Steel is " heavier " than water. Put a small piece of blotting-paper flat on the surface of some water in a dish and gently lay the needle on it. The paper soaks up some water and, after a time, sinks. But the needle is left floating on the surface of the water ! It seems that there is a kind of skin on the water. When you touch the needle you break the skin and the needle falls to the bottom. Pour some water into a jar until the water surface is exactly level with the top of the jar. Can you pour any more water into the jar ? Very carefully pour in a little more water. The water does not overflow ; the top surface curves upwards slightly and holds in the extra water. Again it seems that there is a kind of skin on the surface.

Fig. 44 shows a piece of apparatus which you can make from some bits of wire, a cork, and a screw. The screw is of such a size that the apparatus floats upright with the top of the cork *just* above the surface. Push the cork down with a pencil so that the wire ring is about an inch below the surface and then gently lift the pencil away. The apparatus rises until the wire ring comes to the water surface but it does not break through. There is a skin on the surface.

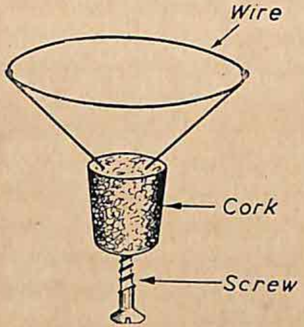

FIG. 44.

There is a skin on the surface of any liquid and a force (perhaps only a small force) is needed to break it. This skin, like that of a soap film, is in tension. It pulls inwards and tries to make the surface of the liquid as small as possible. Unlike the soap film, however, the skin of a pure liquid like water *is made of the same material as the rest of the liquid.* Let us see why there is this skin. Fig. 45 is a simple drawing to show some of the molecules in a liquid. These molecules, we know, are free to move about but there are forces of attraction (pulling-together forces) between them. Think of a molecule which is in

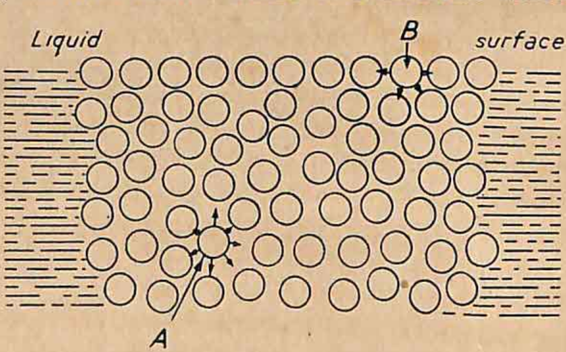

FIG. 45.

the middle of the liquid (like that marked A). It is pulled on all sides by the other molecules round it. These pulls balance each other; they do not make the molecule move in any particular direction. Now think of a molecule which is in the surface (like B). It is pulled by molecules below it and at the sides but there are no molecules above it. The pulls do not balance; together they try to make the molecule B move down into the middle of the liquid. As few molecules as possible, therefore, stay in the surface (some, of course, must stay there), that is, the surface is always as small as possible. So the liquid behaves as if it is covered with a skin which is always trying to pull in and make the surface as small as possible.

Scientists can measure the inward pull of a liquid skin. It can be measured, for example, by finding the size of drops which the liquid forms when it falls from out of the end of a narrow tube. (A liquid with a strong skin can hold together a bigger drop than one with a weak skin.) We call the force in the skin the "surface tension."

Water has a fairly strong surface tension (about 3 times that of alcohol) but the surface tension of mercury (quicksilver) is far bigger than that of any other liquid. It is about 7 times as strong as that of water. That is why mercury forms drops so easily (p. 111). You can try an experiment to show that one liquid has a stronger surface tension than another. Pour a little coloured water into the bottom of a flat dish so that it forms a very thin layer on the bottom.[1] Then, with a pencil point, put one drop of another liquid, such as alcohol (or petrol or ether), in the middle of the water surface. Immediately the coloured water pulls back, leaving a space for the other liquid in the middle. We can imagine that there is a "tug of war."

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[1] Or you can use clear water and scatter sawdust or chalk all over its surface.

Both liquids try to make their surfaces as small as possible. The water pulls outwards to make a space for the other liquid ; the other liquid pulls inwards and tries to keep this space small. But the water has a stronger pull. It makes its own surface smaller and forces the other liquid to spread out.

In some parts of the world, particularly in hot, wet countries, people fear malaria, yellow fever, and similar diseases. Some of these diseases are carried by mosquitoes. The mosquito spends its early life as a larva (kind of caterpillar) living in ponds and pools of still water. It hangs from the skin on the water surface, with its head in the water but its breathing tube sticking out through the surface (Fig. 46). It is held up by the strength of the skin. If oil is poured on the water the surface tension is made less. The larva cannot hang to the skin, the oil enters the breathing tube, and the larva is drowned. Many places have been freed from malaria in this way. (The disease has been got rid of in some other places by draining the ponds so that the larva has no water in which to live.)

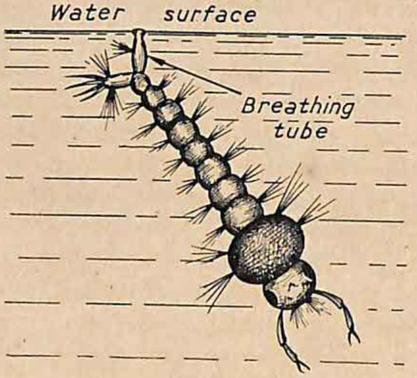

FIG. 46.

We have learned that the surface tension in the skin of a liquid tries to make the surface as small *as possible*. Think of a rain-drop. It is a little mass of water. It is shaped like a ball. The surface tension pulls the water into such a shape that the surface is as small as possible.

Of all the possible shapes, a ball has the smallest surface. But if you pour some water into a cup it takes the shape of the lower part of the cup ; it does not take the shape of a ball. Why not ? We must remember that surface tension is not the only force acting on a liquid. A liquid also has weight. The weight of a rain-drop is very small and the surface tension can force the water into a round shape. The weight of the water in a cup is much stronger than the surface tension. It makes the water go as low as possible in the cup. We can imagine that there is a struggle between surface tension, which tries to make the liquid into a ball, and the weight, which tries to make the liquid flat and low. This struggle is nicely shown by mercury drops. If you spill some mercury on the table you see that the very small drops are almost perfect balls (Fig. 47 *a* and *b*). The surface tension, which is very strong in mercury, is more important than the weight. Bigger drops are fairly round but slightly flattened (see *c* and *d*). Here neither the surface tension nor the weight is more important. Very big drops and small pools have flat tops but rounded edges (see *e*). The weight is now more important than the surface tension. You can often see the same effect if you spill some water on a table which has a greasy top.

Now we come to that strange effect which we call "wetting." If your finger is clean, and you dip it into some water, you say that it is wet when you take it out again. There is a thin layer of water over your finger.

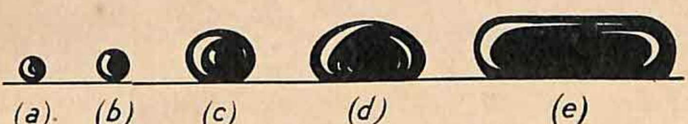

FIG. 47.

Things are wet if they are covered with a film of water. Rub some oil or grease on your finger and dip it into the water. There may be a few drops of water on your finger when you take it out but your finger is certainly not covered all over. It is not wet. The problem of wetting, we see, is really the problem of the spreading of liquids over solids. Why, for example, does water spread over a clean finger and not over a greasy finger ?

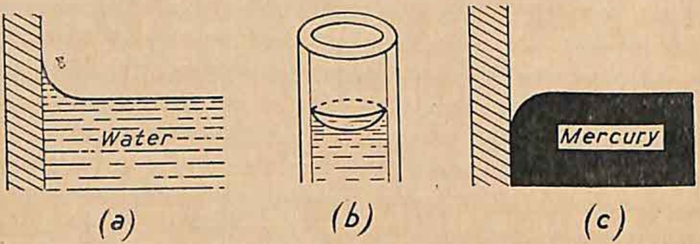

FIG. 48.

Pour some water into a clean glass dish and look carefully where the water meets the side of the dish. The surface is not level there. It curves up towards the glass as shown in Fig. 48 *a*. If the water stands in a very narrow container, or in a tube, the surface curves up all round so that it has the shape of half a ball (see *b*). For this reason it is not easy to see the exact level of liquid in a bottle. Pour some water into a dish whose inside has been rubbed with a greasy rag. The water does not curve up towards the sides, in fact it may actually curve away from the sides. A mercury surface always curves away from the sides of the container (see *c*).

We know there are forces of attraction between the molecules of a liquid. There are also forces of attraction between water molecules and the molecules in the glass. This second force of attraction is so strong that water molecules near the glass are pulled up in a curve towards it. But water molecules are not attracted by oil molecules. So the water surface does not curve up against an oily surface and may even stand away from it.

We can now understand the problem of wetting. Suppose we spill some water on a piece of *clean* glass. The surface tension of the water tries to make the water into round drops; the weight of the water tries to make it spread out. But the forces between the water molecules and the glass are strong and help the water to spread. The water covers the glass, i.e. it wets it. Suppose we spill some water on a greasy piece of glass. There is no attraction between the grease and the water. The water does not spread; it is pulled into round drops by its surface tension. Mercury does not "wet" anything (except certain metals). You can dip your finger into some mercury but when you take it out it is quite dry. Mercury does not spread; it always tries to form round drops.

A woven material, like cloth, is porous. If we pour some water into a cloth bag it soon wets the cloth and runs through. Of late years several kinds of woven materials have been treated with oily substances so that water does not wet them. We can buy, for example, a "rain-proof" coat. The rain, unless it is very heavy, does not easily soak through the coat but air can still pass through the pores. The canvas from which a tent is made keeps out water in a similar way. But if we touch the inside of a tent when it is raining, the water may soak through. By touching we help the water to spread and make its way through the pores.

We commonly use soap when we wash things which are dirty, particularly if the dirt consists of oil or grease. How does the soap help to take away the grease etc.? Pure water does not spread over grease but soapy water can. This is largely because the surface tension of soap solution is much less than that of pure water. Next, the soap solution causes the grease which is set free to form small drops. These can easily mix with the soap solution. Then we can wash the mixture away with some more clean water.

CHAPTER XII

SOLUTIONS AND THEIR PROPERTIES

IF we shake up a few grains of sugar with some water they disappear from view. They lose their solid, crystalline form and mix with the water. We say that the sugar dissolves and makes a solution. The solution is quite clear and colourless, and, in fact, looks like water, but there are several ways of showing that the sugar is there. The solution has a sweet taste ; if we let the water dry up, the sugar is left behind. The solution is a very close mixture of water molecules and sugar molecules.

We can make solutions (in water) of salt, soda, Epsom salts, copper sulphate, and other well-known substances. We say that these substances are " soluble." White solids usually make colourless solutions ; coloured solids make coloured solutions. Thus a solution of copper sulphate, a blue solid, is blue. All such solutions are perfectly clear. We cannot see any particles of the solid floating in the water. Further, we cannot separate the solid from the water by passing the solution through a filter (p. 13). We must boil off the water, or let it dry up, if we wish to get the solid back again. Other well-known substances, such as chalk, sand, and soot, do not dissolve in water. They are " insoluble." If we shake up such a substance with water, little particles may float about in the water for a while, but they gradually sink to the bottom. We can see the particles ; the liquid is not clear. If we pass the liquid through a filter the particles are separated from the water.

A fixed weight of water cannot dissolve more than a certain weight of the solid (at any particular temperature). Thus 100 grammes of water cannot dissolve more than 35 grammes of common salt at ordinary room temperature. We can have a solution with less salt but we cannot have a solution with more. Some substances are more soluble than others. Salt, sugar, and copper sulphate are fairly soluble but lime is only slightly soluble. Usually we can dissolve more solid in hot water than in cold water. About twice as much Chile saltpetre (p. 25), for example, can dissolve in boiling water as in ordinary cold water. Common salt, however, is not much more soluble in hot water than in cold. If a strong, hot solution cools, the water may not be able to hold all the solid. Some of the solid must come out of the solution. Usually the solid re-appears in the form of crystals.

Although the solutions which we know best are made by dissolving solids in water, we can make solutions by dissolving solids in other liquids. A liquid which can dissolve a solid is called a " solvent." Water is a solvent; alcohol, petrol, benzene (from coal tar) are solvents. Sometimes a substance which is insoluble in one liquid is soluble in another. Wax, for example, is insoluble in water but soluble in benzene. You may know the substance called " iodine "; we sometimes put it on a cut or a wound. Iodine itself is a brown-black solid. It dissolves only slightly in water but dissolves well in alcohol. The " iodine " which we put on cuts is chiefly a solution of the solid in alcohol. Turpentine is a well-known solvent for paint.

Let us now think of some of the uses which we make of solutions in the home. We dissolve sugar in tea to make it sweet, and even tea itself is a solution. Common salt often is added to our food in the process of cooking. The food which we eat is changed inside the body into soluble substances and then the solutions can be taken into the body. Blood is a kind of solution. Medicines are usually solutions of drugs. There are several reasons why we take medicines in this form. It is often easier to drink a solution than to swallow a solid, and a solution passes more easily into the blood (to be carried to where it is needed). Next, it is easier to measure out a suitable amount of a solution than a suitable amount of a solid drug. Suppose we need to take 1/2000 gramme of a drug. An ordinary person in the home could not measure out this very small amount correctly. But a chemist can make some medicine by dissolving 1 gramme of the drug in about 14 pints of water (roughly 2000 teaspoonfuls) and tell the person to take one teaspoonful of it. Then the right amount is taken.

Suppose we get a dirty grease mark on our clothes. How can we remove it? We make use of our knowledge of solvents. Grease does not dissolve in water and even soapy water cannot remove a bad mark. Grease dissolves easily in liquids like petrol and benzene. So we can remove the mark by rubbing with a rag soaked in either of these liquids. Similar solvents are used for "dry-cleaning" clothes.

Ordinary oil-paint, like that used for painting the woodwork of a house, consists chiefly of three parts. The *solvent* is linseed oil (obtained from the seeds of flax plants) or turpentine (obtained from the gum-like juice of certain pine trees). Then, of course, there is the *colouring material*. The third part is called the *body*. This is a solid material which helps to "cover" the surface and so give a thick, smooth surface when the paint dries. White lead is commonly used for this purpose. The drying of the paint is a chemical action in which the oil joins with oxygen in the air, forming a kind of skin which holds the colouring material in place and protects the painted surface from the effects of the weather. Varnish is a solution of resin, a gum-like substance, in a suitable solvent like alcohol. It dries by evaporation of the solvent and leaves a thin, shiny skin of resin over the surface.

Another important solvent is one with rather an unfamiliar name—amyl acetate. It has a strong fruit-like smell (particularly like that of the English pear). It is important because it dissolves materials like celluloid (p. 130). Celluloid solution is used for joining and mending celluloid cinema films. Ladies sometimes use a similar solution for making their finger-nails bright and shiny.

Now we must turn to another property of solutions which is important in quite a different way. Let us try some experiments. Take a thin-skinned fruit (e.g. plum, grape, prune) which has become so dry that its skin is wrinkled. Put one in a glass of water and another in a glass of strong sugar solution. Examine them after 24 hours. The fruit in the water swells; it becomes fat and firm. The fruit in the sugar solution becomes smaller and more wrinkled. What has happened? In the first case, water goes into the fruit, through the skin, faster than its juices come out. In the second case the juices come out faster than the sugar solution goes in.

For the next experiment you need an egg—or two if you can spare them! You must try to remove the chalky shell without breaking the thin white skin which lies immediately below it. (This can be done most conveniently by putting the egg in hydrochloric acid (spirits of salt) and dissolving the shell away.) Then wash the egg and put it in a glass of water. After a day or two you find that the egg has become fatter. Water has gone into the egg through the skin. If you put a similar egg in a strong solution (e.g. of salt) you find that the egg becomes smaller; water comes out of the egg.

In both these experiments water passes through a thin skin (the fruit skin, the egg skin). And in both experiments the solution on one side of the skin is stronger than that on the other side. The fruit juices, for example, form a stronger solution than pure water but a weaker solution than the sugar solution. In every case, *water passes from the weak solution, through the skin, into the strong solution.*

Fig. 49 shows another experiment. You need a piece of "cellophane"—the thin, clear paper which is sometimes used for wrapping cigarette packets and for covering the tops of jars of jam. Fold a round piece of cellophane as you folded a filter paper (p. 12) so that it forms a kind of cup. Support it in a wire ring (*a*) so that its lower part dips into a jar of water (*b*). Pour some strong sugar solution into the cup and mark its level. Leave the apparatus for about 24 hours. You find that the level of the liquid inside the cup has risen. Water has passed through the cellophane into the stronger solution inside.

We learn, then, that when two solutions are separated by a skin (of certain kinds), water passes through the skin

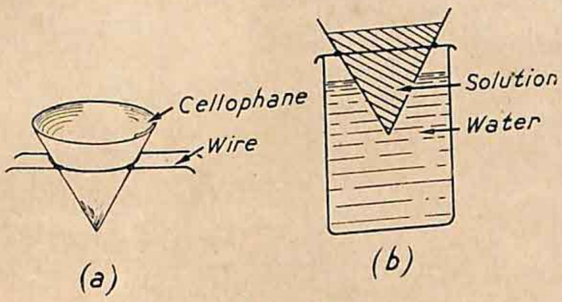

FIG. 49.

from the weaker solution into the stronger solution. This effect is called " osmosis."

What is the particular importance of osmosis? It is the method by which plants take in water from the soil. If you carefully examine the root of a plant, particularly the root of a little plant newly grown from the seed, you can sometimes see little " root hairs " on it. A plant is made up of many little " boxes " called cells. These little cells can be seen if you use a microscope to look at a thin piece cut from a plant. Fig. 50 *a* shows the cells as seen in a piece of a young root which is cut across. The root-hairs are cells on the edge which have grown out long and thin. The walls of cells are made of a tough material called cellulose about which we shall read more in the next chapter. Inside there is a layer of jelly-like material called protoplasm. This is the *living* part of the

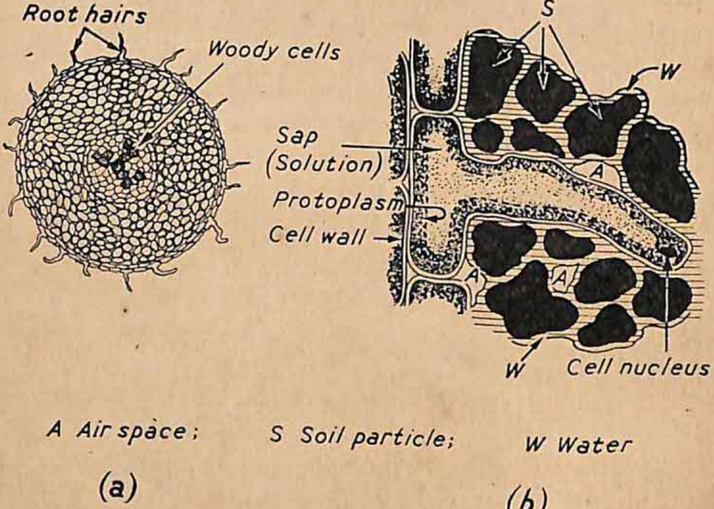

FIG. 50.

cell. The middle of the cell is filled with a juice which consists largely of sugar solution. You can see these parts in Fig. 50 *b*. The layer of protoplasm acts like a skin. Inside it there is a strong solution; the water in the soil, which soaks through the cell-wall, is a weak solution. So water passes through the protoplasm skin by osmosis. In this way the root takes in water from the soil.

A solution of sugar, or salt, or copper sulphate, is quite clear. We cannot see particles of solid floating about in it. We must now turn to solutions of rather a different kind. Let us try to make a solution of starch. Grind a little starch with a small amount of water and so make a kind of paste. Then add some boiling water and stir well. Pour off the liquid into another container. Is it a solution? It is not perfectly clear; it has a pale white, cloudy colour. But you cannot see the particles of solid. We have difficulty in deciding whether to call it a solution or not. Put a little powdered glue in a jar, add some boiling water, and stir. You make a pale brown liquid. It is not perfectly clear and yet you cannot see particles of solid in it. The white part of an uncooked egg is another such liquid.

If we shake up an insoluble solid (such as chalk) with water, we do not make a solution. We can see the particles of the solid floating about in the water. After a short time the particles sink to the bottom. If we shake up some soil with some water, the bigger particles sink to the bottom fairly soon, but the liquid remains pale brown in colour and cloudy for several days. The very small particles of mud sink *very* slowly. These particles may be too small for us to see. Is it possible, then, to have solid particles in water which do not really dissolve but are so small that *never* sink to the bottom? Yes. That is what we have when we make a " solution " of starch or of glue. The solid is broken up into very small particles, perhaps only one ten-millionth of an inch across, which float about in the water and never sink. Such solutions are called " colloidal solutions " (from the Greek word *kolla* which means " glue ").

Almost any non-crystalline substance which does not dissolve easily can be made into a colloidal solution. It is possible, for example, to make a colloidal solution of gold. The solution has a purple colour. The particles in such solutions consist of little groups of molecules (and not separate molecules as in most true solutions). But the colloidal solutions which we know best are those of substances like starch, glue, rubber (you know the " solution " for sticking patches on a bicycle tyre), and egg-white. All of these substances have very big molecules (p. 125). Substances with very big molecules cannot form true solutions but they often form colloidal solutions.

Add a *small* amount of water to a little starch and warm the mixture carefully until it forms a thick, white liquid. Then allow it to cool. The starch forms a blue-white jelly. The jelly is merely a colloidal solution which contains so little water that it cannot run like a liquid. We can imagine that it consists of an uneven mixture of big starch molecules and small water molecules. You remember that, in Chapter II, we wondered whether to call a jelly a solid or a liquid. We now see that it is a special kind of mixture of a solid with water. If we warm a little of a jelly with some water it loses its firmness and becomes a colloidal solution. If a colloidal solution loses enough water it sets to a jelly again.

Colloidal substances are of great importance in everyday life, and, indeed, in the very process of living. Much of our food consists of colloidal substances. Bread and potatoes, for example, consist chiefly of starch. Protoplasm, the actual living part of plants and animals, is a colloidal jelly. The various kinds of gums and pastes which we use for sticking things together are colloidal solutions or colloidal jellies. Soap is really a thick kind of jelly and a photographic film is a very firm kind of jelly. When some colloidal solutions are heated the very small particles join together and form bigger particles. Then the solid appears. This is what happens when you fry an egg ; the egg-white becomes a thick, white solid.

Milk is a good example of another kind of colloidal solution. It consists chiefly of very small drops of fat in water. It is a colloidal solution, not of a solid, but of a liquid (fat). We call such a colloidal solution an "emulsion." The fatty parts of our food are made into emulsions inside the body before they can be taken into the blood. Soap forms an emulsion with grease when we use it for washing (p. 114). A spider makes an emulsion when it spins its web ; the emulsion dries and forms a thread. Silk threads, both those made by a silkworm and those made artificially (p. 129), are also dried emulsions.

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CHAPTER XIII

MAN MAKES NEW MATERIALS

IN the course of this book we have read about many useful materials. Some of these materials are obtained from the rocks. Clay, for example, is found in the ground ; metals, such as iron and copper, are obtained from ores. Other materials are obtained from plants and animals. We have read about cotton, rubber, silk, leather, turpentine, and so on. Man cannot hope to *make* iron ; iron is an element. He might succeed in making some of the simpler compounds obtained from the rocks (e.g. chalk) if he started with the right elements, but it is easier and cheaper for him to dig up the materials from the ground. But it might be an advantage to him to make some of the plant compounds, or animal compounds, from simpler materials. Rubber, for example, is a compound of hydrogen and carbon. These are very common elements. If he could make rubber from these elements he would not need to depend on the rubber plant. The compounds forming many plant materials, such as starch, wood, and cotton, consist of the three elements hydrogen, carbon, and oxygen, and many other compounds, obtained from both plants and animals, consist of these elements and nitrogen. Our problem is this : Can Man copy Nature and make plant and animal materials from simple substances ?

Scientists have found out how the atoms are arranged in the molecules of many plant and animal materials. They know, for example, how the carbon, hydrogen, and oxygen atoms are arranged in a molecule of starch. But, strangely, all these molecules found in plants and animals are very big, complicated molecules. We read in the last chapter that starch molecules are so big that they cannot properly mix with water to form a true solution; in Chapter VII we read that cotton fibres consist of long, thin, chain-like molecules. We can call such complicated molecules " giant molecules," for, compared with simple molecules like those of water, copper sulphate, etc., they are like giants. It would seem that Man has a very difficult problem to copy nature and make such molecules.

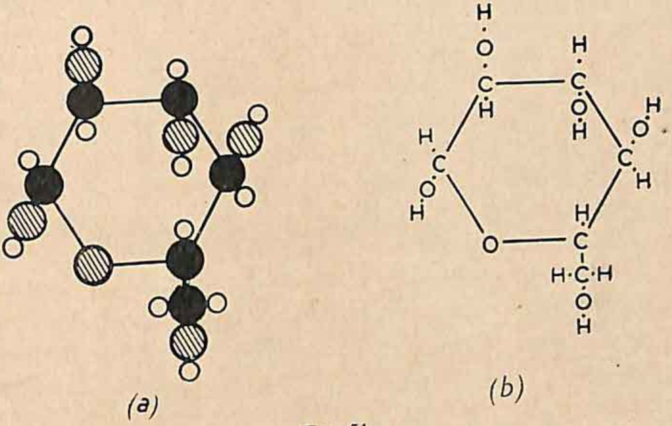
But the problem is not quite so difficult as it seems at first. Suppose a wild man, who had always lived in the forests and made his " home " in caves, came to one of our big cities. He might look at our houses and other big buildings and think that he could never make such complicated things. But, after long examination, he would see that these buildings are chiefly made of bricks joined together. He might say " If I can get a supply of the right sort of bricks, and find out how to join them together, I could build a house." A house is a complicated building made chiefly of simple bricks. Many giant molecules are something like houses. They are built up from simpler molecules. The starch molecule, for example, is a chain built up from molecules of a simple kind of sugar. The " bricks " (the sugar molecules) are joined together in a row. In trying to make such materials, Man must get a supply of the right kind of bricks, which often is fairly easy, and then find out how to join them together in the right way, which usually is much harder. If he can do this he can make the material.

In this chapter we shall read about some of the materials which Man has tried to make in this way. We shall have to use some chemical names but that should not worry you. Learning the name of a chemical is no harder than learning the name of your friend's dog! Some names are given in brackets. These are the less important names and are given only for those of you who are specially interested.

Let us start with one of the chief materials of which plants are made. We learned in the last chapter that both plants and animals are made up of cells. Plant cells, unlike animal cells, have cell-walls and these walls are made of a material called cellulose. All things made from the *body* of a plant (not the protoplasm and juices inside the cells) consist largely of cellulose. It forms, for example, the greatest part of wood, cotton, and flax, and, therefore, of materials made from them, such as paper, linen, and string. The cellulose molecule is a " giant " molecule. Because of the very great use of cellulose materials, scientists have tried to find out how this giant molecule is built up from simpler molecules.

In our study of cellulose we begin, perhaps surprisingly, with sugar. The sugar which most of us best know is the kind which we use to sweeten our food. It is obtained from the sugar-cane and from the root of the sugar-beet. But this kind of sugar is only one of many kinds of sugar which are found in nature, and it is not the simplest kind of sugar. Another, simpler kind is found in the juice of grapes and certain other fruits. The proper name for grape-sugar is glucose. It is sweet, like cane-sugar, but does not form nice crystals. Fig. 51 *a* shows a glucose molecule. You can see that there is a ring made of 5 carbon atoms (black) and 1 oxygen atom (shaded); other atoms, chiefly hydrogen and oxygen atoms, are joined to this ring. Fig. 51 *b* shows how the scientist uses letters to represent the molecule. It is a big molecule compared with a water molecule but not a " giant " molecule.

The glucose molecule is the unit (or " brick ") from



(a) (b)

FIG. 51.

which cellulose is built up. Look at Fig. 52. This may seem to be very difficult and complicated but we shall soon understand it. There are two glucose molecules side by side. Now suppose that, in some way, the two hydrogen atoms and the oxygen atom shown inside the broken line join together and make a separate molecule. You know that this is a water molecule (H_2O). The two parts of the

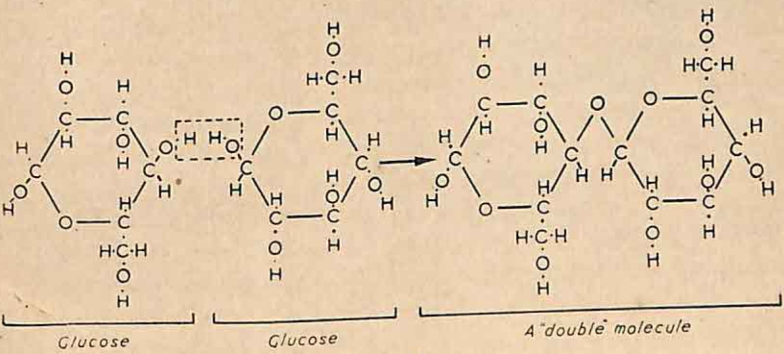


FIG. 52.

glucose molecules join together, as shown on the right, to make a bigger molecule. This " double " molecule is another kind of sugar. Cane-sugar is a double molecule but slightly different from the one shown. If a third glucose molecule can be made to join, in a similar way, with a double molecule a compound consisting of three units is formed. Bigger and bigger molecules can be built up in this way.

A molecule of starch is probably built up from about 26–30 glucose units. These big, awkward molecules cannot move about freely. They do not arrange themselves into a pattern and so form a crystal ; they do not mix well with water molecules to form a true solution. The starch in the food which we eat must be broken up into glucose (by liquids in the mouth and stomach) so that it can dissolve and pass into the blood. A cellulose molecule is even more complicated. Some scientists think that it is built up from about 150 glucose units but others think that the number is nearer 1,000. What great molecules these are !

Cellulose fibres, of various kinds, are so useful to Man that he might well wish to make cellulose himself from simpler materials. What, exactly, does he want ? Most of the fibres which he obtains from plants (e.g. cotton fibres) are rather short. They must be well twisted together to make a useful thread. The only natural long fibres are those of silk, which may be a few hundred yards long, but silk is not cheap or plentiful. What Man really wants, then, are long, cheap fibres.

Man is not able to copy nature by building the giant cellulose molecules from the simpler glucose molecules ; he has found out, however, how to make long fibres from cellulose already made by plants. There are several ways of doing this. All of them depend upon dissolving cellulose in something to make a sticky " solution " and then pressing it through a very small hole to make a thread. The threads, when dry, are smooth and shiny like silk, but, of course, they consist of cellulose and not of the material made by the silk-worm. Such threads are called " artificial silk " or " rayon." The threads can be woven into various kinds of cloth and used for dresses, curtains, and ladies' stockings. Cellophane (the thin, tough, clear kind of paper used for wrapping sweets, etc.) is a similar material. It is made by pressing the sticky solution through a thin slit or by rolling it.

Almost exactly a hundred years ago a certain Englishman was trying to find a way of making a material like horn (e.g. the horn of a cow). He started with a substance called nitro-cellulose which is made by dissolving cotton in nitric acid. (One of its uses is for making certain explosives.) He dissolved some nitro-cellulose in a mixture

(By courtesy of Messrs. Courtaulds Ltd.)

Manufacture of artificial silk. The softened wood is put in a press before it is treated with caustic soda.

(By courtesy of Messrs. Courtaulds Ltd.)

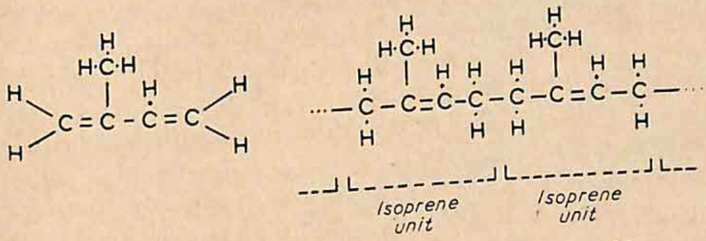
The man is removing a " cake " of artificial silk from a spinning box.

of alcohol and camphor. To his delight, it formed a hard, horn-like mass. He had made a material something like that made by an animal. We now call this material "celluloid." It is similar to glass, though not quite so clear, but has the useful property of flexibility (able to bend). At one time it was used for making children's toys, such as dolls, but it is a dangerous material for such uses because it burns easily. The chief use now is the making of photographic and cinema films. When you think of the great part that such films play in our modern life, you realise how important celluloid is. The useful properties of celluloid are its clearness and flexibility

Another kind of celluloid is now made by first treating the cellulose with vinegar acid (acetic acid) instead of nitric acid. This kind of celluloid has the advantage that it does not burn with a flame. It is used for small cinema films but is not strong enough to withstand the wear which big moving-picture films get. Other kinds of artificial silk and Cellophane are also made from this material.

Now we will turn to another very important and useful material: rubber. Rubber is obtained from the juice of the rubber tree which grows in certain hot, damp countries (especially Malaya). The juice consists of small drops of rubber in water. By a suitable process these drops can be made to join together and form a tough, elastic mass. After this raw rubber has been treated with a small amount of sulphur, it becomes harder and able to withstand much wear. The chief use of rubber, of course, is for making tyres.

When rubber is heated it forms an oily liquid with the smell which we usually describe as "burning rubber." This liquid is called isoprene. (We shall need this name while we are reading about rubber but you need not learn it unless you wish.) A molecule of isoprene is a fairly simple one consisting of 5 carbon atoms and 8 hydrogen atoms (Fig. 53). The long, thread-like molecules of



Left: Isoprene molecule. *Right:* Isoprene units as in rubber. (There is a reason for the "double" joins between some of the atoms but it does not concern us here).

FIG. 53.

natural rubber are built up from isoprene molecules. Rubber trees only grow in certain countries and, particularly in war-time, other countries may not be able to get all the rubber they need. So, as you might guess, scientists have tried to copy nature by building up the giant rubber molecules from the simpler isoprene molecules.

Scientists have discovered a way of making isoprene molecules join together to form rubber, and, as they can make isoprene from cheap materials, they can make all the rubber they need. This artificial rubber is just as good as natural rubber. But the scientist has been able to do even better than Nature. By starting with other substances similar to isoprene, he has been able to make new kinds of rubber which are not found naturally. Some of these artificial rubbers are better than ordinary rubber. Man has actually made *new* materials with the properties which he wants.

In almost every home, in all parts of the world, there are things made from materials commonly called Plastics (or, sometimes, Bakelite). It is a hard, horn-like material, often brown or dark-coloured, but may be brightly coloured or even clear like glass. It is used for door-knobs, cups and plates, lamp-shades, fountain pens, electric light fittings, radio " boxes "—in fact a man once said that one day we shall build our houses with Plastic and make all the things inside with the same material.

The first Plastic material which was made was Bakelite. (That is why many people use the name Bakelite for all kinds of Plastics.) This hard solid, strangely, is made from two liquids : phenol (sometimes called carbolic acid and used as a strong disinfectant) and formaldehyde (often sold, weakened with water, as " formalin "). If these two liquids are mixed together and heated nothing much

(*By courtesy of Bakelite Ltd.*)

Boxes and other containers moulded from Bakelite plastic.

happens. But if, before heating, a few drops of ammonia are added, a surprising change takes place after heating for a short time. The mixture swells and forms bubbles, and then two liquids separate; one yellow and one colourless. The colourless liquid is water. When the yellow liquid is separated from the water and allowed to cool it forms a hard solid like "resin." (Resin, of course, is a sticky gum-like material obtained from a tree; it hardens to a yellow glass-like solid.)

What has taken place? A "giant" molecule has been built up from simpler molecules. Fig. 54 shows how this giant molecule is built up. A phenol molecule, as you see, consists chiefly of a ring of 6 carbon atoms. There are 6 hydrogen atoms and 1 oxygen atom. The formaldehyde molecule is simpler. The drawing shows how a formaldehyde molecule joins together the two phenol molecules. Two hydrogen atoms join with an oxygen atom and form water. The ammonia enables this change

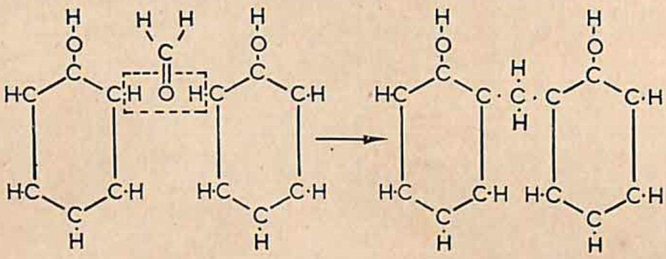
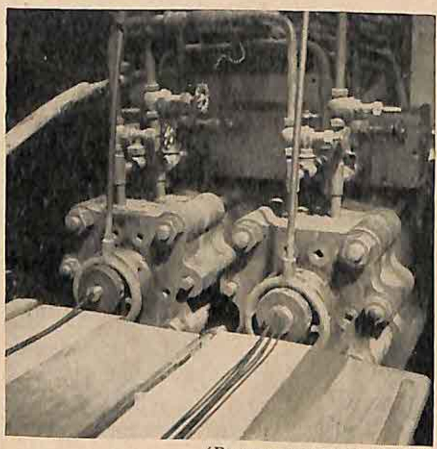


FIG. 54.

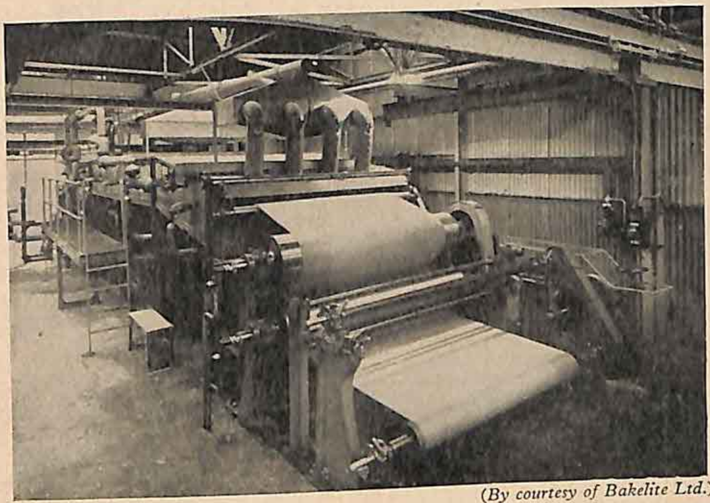
to take place. Clearly a long chain can be built up in this way, and the chains, by cross joins, can be built into a network. We get a giant molecule. Although the material is similar to the resin obtained from the tree it is not quite the same. It is completely an artificial material.

At first the resin-like material was used for making varnish (p. 118) but in 1916 a further use was discovered.



(By courtesy of Erinoid Ltd.)

Making casein plastic rods by forcing the soft material through small holes.

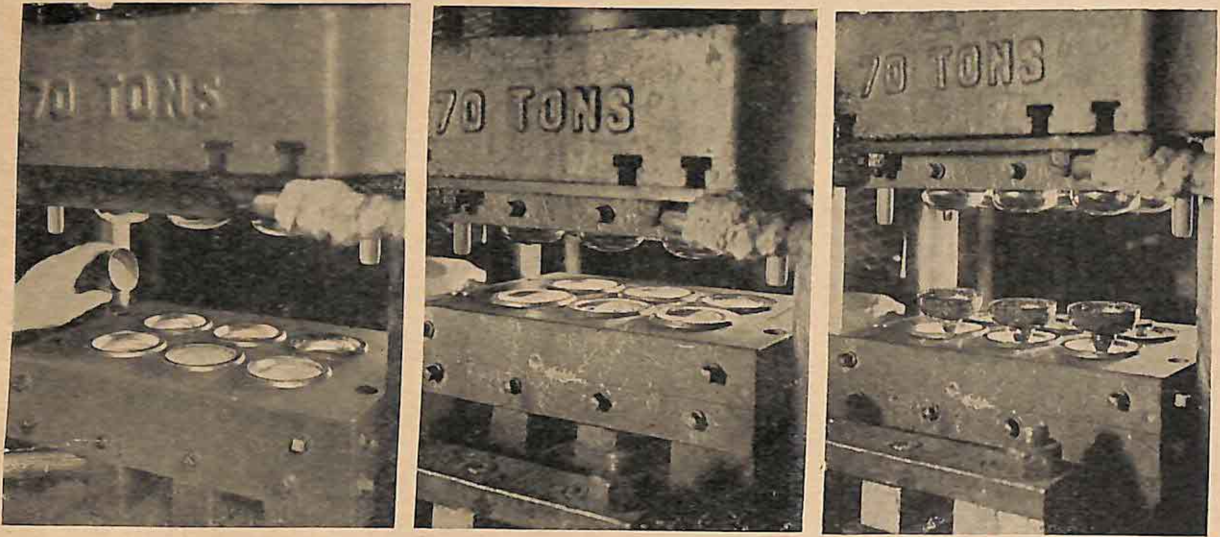


(*By courtesy of Bakelite Ltd.*)

Making Bakelite "laminated sheet." In this machine paper or other fibrous material passes through a solution of the plastic. After drying, a number of sheets are pressed together to make a firm board.

The resin is mixed with fine sawdust (or other "filling" material) and gently heated for some time. It forms a harder material which, however, can be softened by heat. This, when ground into a powder, is called "moulding powder." You know how things are made by moulding. If you pour some melted wax into a small cup, it cools and forms a solid of the shape of the inside of the cup. Many iron things are made by pouring melted iron into a shaped "mould." The Bakelite moulding powder can be made into a soft sticky mass and shaped in a mould. In this way various things can be made.

Bakelite and similar Plastics made from phenol have one disadvantage. They are dark in colour. Other kinds of Plastics are now made from other materials. The Plastics of one kind are nearly colourless. By adding

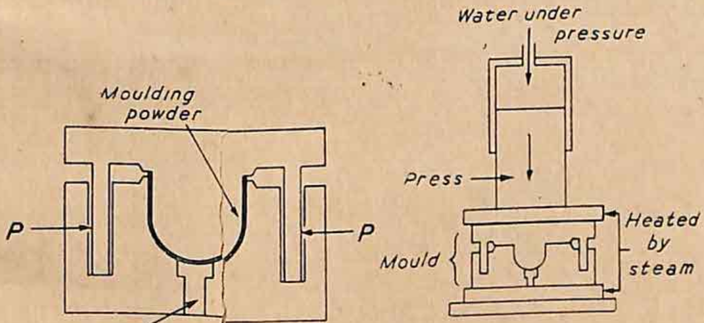


(*By courtesy of Bakelite Ltd.*)

Making plastic pin bowls. *Left :* measured amounts of moulding powder are poured into the six moulds. *Middle :* the upper part of the press is about to come down. *Right :* the press has opened again and the bowls are pushed out of the moulds.

suitable colouring material, Plastics of almost any desired colour can be made. There are other Plastics which are like glass. They are already used for making lenses for cameras and microscopes. They are not quite so hard as glass and can therefore be scratched more easily but they are less brittle.

By now you have guessed why these materials are called Plastics. All these materials, at some time, are soft so that they can be shaped by heat and pressure. Some Plastic things can be softened again by heat but most, after they have been made, cannot be softened again. The material, when soft and plastic, can be shaped in several ways. The most common way is by moulding. Fig. 55 shows how a simple thing like a cup is made. Drawing (*a*) shows the mould. It consists of two parts. The right amount of moulding powder is put in the hollow in the lower part and then the upper part placed in position. Notice the pegs P which make sure that the upper part stands at the right height. The powder is heated and the two parts pressed together. Drawing (*b*) shows how this is done. A hydraulic (water-power) press



(*a*) (*b*)

FIG. 55.

is used and the plates above and below the mould are heated either electrically or by having steam passed through them. After the two parts of the mould have been separated again the little pin R is pushed up to lift the cup from the mould.

One of the most interesting silk-like Plastics is called Nylon. It is made from substances containing nitrogen (in addition to carbon, hydrogen, and oxygen). It is more elastic than true silk and stronger than both true silk and artificial silk. Most ladies like to have Nylon stockings. It is also used, instead of hair, for various kinds of brushes and for the ropes of parachutes (by which airmen can jump from an aeroplane).

Perhaps the most complicated natural material is protoplasm. This is the *living* part of a plant or animal. Man has not yet been able to make protoplasm. If he could make it he would make something which is alive !

With our story of new materials made by Man we must finish our little book. We have studied the chief properties of various materials. Man has learned how to use these materials to help him with his work and to add to his pleasure and comfort. Scientific knowledge, if properly used, can make our lives more useful and more pleasant.

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